Range
Commanders
Council

TECHNICAL REPORT

CONFERENCE ON
COHERENT RADARS FOR
RANGE INSTRUMENTATION

5-7 MARCH 1974

CONFERENCE ON
COHERENT RADARS FOR RANGE INSTRUMENTATION

5-7 March 1974

Space and Missile Test Center
Vandenberg Air Force Base, California

Published by

Secretariat
Range Commanders Council
White Sands Missile Range
New Mexico 88002

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INTRODUCTION

A conference on Coherent Radars for Range Instrumentation took place at the Space and Missile Test Center (SAMTEC), Vandenberg AFB, California, from 5-7 March 1974, under the aegis of Range Commanders Council Executive Committee Member Mr. Stan Radom (Technical Director, SAMTEC). The theme of the conference concerned "what has been the past performance and what is the future potential of Coherent Radars for test support instrumentation." In addition, emphasis was placed upon preparations for the upcoming GEOS-C launch.

This publication contains outlines and excerpts from the various conference briefings. Names and addresses of conference presenters precede each of these synopses. It is intended that this document provide a means for obtaining additional dialogue and input in the area of Coherent Radars.

UNOFFICIAL ATTENDANCE

NAME	ORGANIZATION
A	
Anders, Bill	TRW
Allendorf, Jr	SAMTEC/ROPM
B	
Baltzell, Leonard, Lt Col	SAMSO/MNN
arber, David	Kentron
eers, Larry, Maj	Def Mapping Agency
Belgin, John	PMR
enn, Don	SAMTEC/ROSF
erbert, John	NASA
Bornholdt, John	RCA
Borrego, Arturo	WSMR
owles, Lee	FEC
Brewer, Martin, Col	AFETR
Brooks, Dr.	FEC
rooks, Ronald	EG&G
Bryant, J.C., Maj	SAMTEC/ROPR
C	
ain, Jerome	PMR
Calhoun, John, Col	SAMTEC/RO
Carney, DeVere	RCA
arpenter, Richard	PMR
Chandler, Terry	Autonetics
Chesebro, Ellsworth	SAMTEC/ENY
in, Ball	WSMR
Cianciotto, Andrew	TRW
Cockerham, Frank	RCA/AFETR
leman, Lt Col (USAF)	Army /KRD
Collins, Bill	FEC
Conley, John, Col	SAMTEC/ROO
llen, Frank, Col	SAMTEC/ROP
thbert, William	SAMTEC/ENI
D	
I Does, D., Maj	SAMTEC/ROCA
Dempsey, Donald	RCA
Donohue, G.	SAMTEC/ROCA
I 'al, T., Capt	SAMTEC/ROSO
E	
E augh, Lawrence	AFETR
E cksen, D.	SAMTEC/ROCA
F	
F gerlin, Virginia	FEC
Favreau, Nelson	Motorola
Ford, Thomas	PMR
F rest, Dan	FEC
Frederick, John A.	PMR
Fuller, Ray	FED

NAME	ORGANIZATION
G	
Gossett, Oscar	NWC
Graves, Ken	SAMTEC/ROOE
Green, Robert	WSMR
Greene, John	RCA/AFETR
Guyton, Charles	PMR
H	
Hageman, Herman	Motorola
Hagin, Dr.	FEC
Hall, Edgar	FEC
Hargrove, Wilbur, Maj	SAMSO/MNN
Hass, Don	SAMTEC/ENI
Hawkins, William	NASA
Hedricks, C. W.	SAMTEC/ACD
Henry, Joe	Westinghouse
Hillhouse, Milton	AFETR
Hoops, Leonard	FEC
Hopkins, Dr.	FEC
J	
Jackson, Ben	NASA
Jantz, Jr	SAMTEC/ROSF
Jasen, F., Lt Col	SAMTEC/ROPR
Johns, Milton	SAMTEC/ENI
Johnson, Roger, Col	SAMTEC/ROC
Jones, Neil	SAMTEC/ROKE
K	
Karbin, John	FEC
Keeney, Tom	Army/KRD
Kennedy, John	RML/AFETR
Kennett, Grover	Motorola
Knox, Sidney	PMR
Krabbenhoeft, Bob	FEC
Krabill, Bill	NASA
Kranz, Edward	TRW
Krieger, Bill	SAMTEC/ROPM
Kroeger, Otto	WSMR
L	
Lambson, Richard	Motorola
Lanan, Lt Col	SAMTEC/XPP
Latimer, Ellis, Capt	AFETR
LaVance, Cecil	Motorola
Lichter, Dr.	FEC
Lubar, Bertram	AFETR
Lyon, H.	SAMTEC/ROPR
M	
Macy, Stephen	N Amer Rockwell/OOAMA

NAME	ORGANIZATION
Manning, Walter	AFETR
Martin, John	ADTC
McGraw, William	SAMTEC/EN
Mefford, C.W.	FEC
Meer, M., Capt	SAMTEC/ROSO
Meyers, R.L.	FEC
Mitchell, Renzo	RCA
Mizuki, Dr.	FEC
Moulds, T.	SAMTEC/ROST
Myers, Robert	Boeing
N	
Nefzgar, C., Capt	SAMTEC/ROCA
P	
Parker, Horace	RCA
Pass, Jack	Army/KRD
Paulus, Bill	Sandia Labs
Pease, C	SAMTEC/ROPP
Pike, Robert	NASA
Porter, E., Lt Col	AFETR
Preston, Robert, Lt	AFETR
Pryor, William	Vitro
R	
Reck, Harold	SAMTEC/XPT
Reed, Gary	FEC
Relf, Kenneth	RCA/AFETR
Rickard, John	AFETR
Rollins, Clarence	AFETR
Roy, Normand	EG&G
Roy, Russell	FEC
S	
Saladino, R.	SAMTEC/ROCA
Samborsky, Lt Col	SAMTEC/XPD
Sayers, Herb	FEC
Schelonka, E., Lt Col	AFETR
Seestedt	SAMTEC/ENI
Selser, Alan	NASA
Speer, Verl	TRW
Spotts, Steve	WSMR
Steiger, R.J.	SAMTEC/XPD
Stanley, Ray	NASA
Sylvestre, Hector	AFETR

NAME	ORGANIZATION
T	
Tapp, Jim	FEC
Taylor, R	SAMTEC/ROPM
Thomason, Tom	SAMSO/MNN
Thompson, Dr.	FEC
Thompson, William	SAMTEC/ENI
Tolman, Wallace	PMR
Torres, Willis	TRW
W	
Walsh, M.	FEC
Walters, Maj	6595MTG
Warren, John	TRW
Watts, Dwight	SAMTEC/XPP
Weinstein, G., LtCol	SAMTEC/ROS
Wells, William	EG&G
Whitcombe, David	Aerospace
Williams, Tal	FEC
Wilson, Gordon	PMR
Woosley, David	FEC
Z	
Zirpoli, D	SAMTEC/ROK

ADDED NAMES

Myers, Robert G	Boeing, VAFB
Webber, D.A.	TRW, Redondo Beach
Wise, Wesley L.	FEC/ITT
Geisinger, R.	SAMTEC/ROS
Toomey, R.	SAMTEC/ROS
Morgan, Donald	Vega Corp
Patrick, John	Sandia Labs
Spence, Robert	Sandia Labs
Viele, Donald	Boeing
Arlowe, Herbert	Sandia Labs
Wood, Clyde	WSMR
Herzog, T.	TRW
Staicano, Capt	SAMTEC/ROPM
DeNicolai, Mr.	TRW
Butler, A.F.	TRW
Durham, C.	TRW
Semelka, F.	TRW
Wilcox, L	TRW
Haber, Jerry	J.H. Wiggins
Gabler, R.T.	J.H. Wiggins
Boyles, Irvin	AFFTC
Sehnert, P.J.	AFFTC
Grinnel, F. Hugh	FEC
Hines, Mr.	NASA

AGENDA

SAMTEC CONFERENCE ON COHERENT RADARS FOR RANGE INSTRUMENTATION

5-7 March 1974, Bldg 7000 Theatre
Vandenberg AFB, California

0900, 5 March

Coherent Radar as a Range and Range-Rate Instrumentation System —
Robert Green, White Sands Missile Range (WSMR)

Evaluation of Range-Rate Data —
Ball Chin, WSMR

Coherent Data Summary —
Bill Krabill, NASA

C-Band and TRANET Tracking Biases Relative to Collocated Lasers —
John Berbert, NASA

1330, 5 March

Influence of Range-Rate Data on ICBM Instantaneous Impact Prediction Errors —
Russell Roy, FEC

Doppler Track Evaluation--Operational Data —
Virginia Fagerlin, FEC

Coherent Signal Processing Experience at SAMTEC —
Bill Collins, FEC

Comments on SAMTEC Coherent Tracking Data —
Maj Tom Thomason, SAMSO

0900, 6 March

Problems Associated with Development of a Launch Head Range Safety System for Containing ICBM Launches in the Kwajalein Lagoon Corridor —
Stan Radom, SAMTEC

Accuracy Requirements for Minuteman Ballistic Missile Tracking —
Maj Tom Thomason, SAMSO CLASSIFIED

Engineering Improvements for Coherent Radar Tracking —
Renzo Mitchell, RCA

GEOS—C Mission Objectives/Profile —
Ray Stanley, NASA

1330, 6 March

GEOS–C C-Band Data Handling –
Bill Krabill, NASA

GEOS–C C-Band Operations/Support –
Ben Jackson, NASA

GEOS–C Coherent C-Band Transponder Technical Characteristics –
Alan Selser, NASA

Defense Mapping Agency Test Objectives for GEOS-C –
Maj Larry Beers, DMA

Conference Summary and Group Discussion on "Where do we go from here?"

0900, 7 March

Meeting of members of GEOS–C C-Band Working Group –
Chairman, Ben Jackson, NASA

GENERAL INFORMATION

1. The telephone number to be used for receiving telephone messages is (AUTOVON 276-6190); (COMMERCIAL 805-866-6190). Telephone is located in the hall immediately outside the entrance to the theatre in Bldg 7000.

2. There will be a military bus available for use to and from the Officers Club for lunch.

3. Various telephone numbers are listed below:

   Scheduled Airline Ticket Office (SATO), Rm C-105, Bldg 11777: 734-4381
   Vandenberg Motel, Lompoc: 736-5605
   Vandenberg Inn, Santa Maria: 922-6631
   Village Inn, Vandenberg Village: 733-3571
   Limousine Service to airport: 736-3636
   Airways Rent-a-Car, Lompoc: 736-8521
   Airways Rent-a-Car, Santa Maria: 922-1994
   Hertz Rental Car, Santa Maria: 925-1305
   Army Liaison Office: 276-7442/6907
   NASA Western Office, SVAFB: 275-3024
   Base Taxi: 276-5711

4. Mail can be received in care of the Technical Director, SAMTEC/CA, Vandenberg AFB, CA 93437

APPENDIX A

COHERENT RADAR AS A RANGE AND RANGE-RATE INSTRUMENTATION SYSTEM

BY

ROBERT E. GREEN
Systems Management Division

And

WILLIAM L. SHEPHERD
Research Projects Office

Instrumentation Directorate
US Army White Sands Missile Range, New Mexico 88002

I. INTRODUCTION

US Army White Sands Missile Range (USAWSMR) has nine coherent radars in its instrumentation inventory. The locations of these radars were chosen to provide good geometry when this equipment is used as a range and range-rate instrumentation system. The measurements of range and range-rate have inherent properties which are desirable for instrumentation purposes. The magnitude of the errors present in these measurements are relatively independent of the distance to the target. This paper outlines the preliminary results of an evaluation of the USAWSMR coherent radars as a range and range-rate instrumentation system. Two methods of processing range and range-rate data were developed for this evaluation. The first method developed inputs range and range-rate from three or more coherent radars and outputs rectangular Cartesian components position and velocity. The second method inputs range and range-rate from three or more coherent radars, filters the range and range-rate data, performs a numerical differentiation to obtain range acceleration, and outputs rectangular Cartesian components of position, velocity, and acceleration. This paper includes a description of the techniques developed and an example of some data processed using the techniques.

II. POINT ESTIMATION - THREE STATIONS

In this section, the simple and geometrically pleasing notation of three dimensional vector analysis is used. The solutions obtained here are used in Sections III and IV to obtain start vectors for the Gauss-Newton iteration for the N-station data processing techniques.

Let 0, A, B be three noncollinear points from which measurement of range to a point P is made. Let R_1, R_2, R_3, respectively, denote the range from 0, A, B, respectively, to P, and $\vec{A}$, $\vec{B}$, respectively, the vectors from 0 to A, B, respectively. It is shown* that $\vec{P}$, the vector from 0 to P, is

$$\vec{P} = a\vec{A} + b\vec{B} + c\vec{C}, \quad \vec{C} = \vec{A} \times \vec{B} \quad , \tag{2.1}$$

with

$$a = \frac{\alpha|\vec{B}|^2 - \beta(\vec{A}\cdot\vec{B})}{|\vec{C}|^2} \quad , \tag{2.2}$$

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*Larry Armijo, "Determination of Trajectories Using Range Data From Three Noncollinear Radar Stations," US Army Signal Missile Support Agency, US Army White Sands Missile Range, NM, 1960.

$$b = \frac{\beta|\vec{A}|^2 - \alpha(\vec{A}\cdot\vec{B})}{|\vec{C}|^2} \quad , \tag{2.3}$$

$$c = \frac{(R_1^2 - a\alpha - b\beta)^{1/2}}{|\vec{C}|} \quad , \tag{2.4}$$

where

$$\alpha = \frac{1}{2}(R_1^2 - R_2^2 + |\vec{A}|^2) \quad , \tag{2.5}$$

$$\beta = \frac{1}{2}(R_1^2 - R_3^2 + |\vec{B}|^2) \quad . \tag{2.6}$$

With $(a_1^{(i)}, a_2^{(i)}, a_3^{(i)})^T$, $i = 1, 2, 3$, respectively, denoting the coordinate vector of $\vec{A}$, $\vec{B}$, $\vec{C}$, respectively, with respect to a rectangular Cartesian coordinate system with the same handedness as $\vec{A}$, $\vec{B}$, $\vec{C}$ and with origin at 0, (2.1) can be written as

$$x_1 = aa_1^{(1)} + ba_1^{(2)} + ca_1^{(3)} \quad , \tag{2.7}$$

$$x_2 = aa_2^{(1)} + ba_2^{(2)} + ca_2^{(3)} \quad , \tag{2.8}$$

$$x_3 = aa_3^{(1)} + ba_3^{(2)} + ca_3^{(3)} \quad , \tag{2.9}$$

where $x = (x_1, x_2, x_3)^T$ is the coordinate vector of $\vec{P}$.

With ρ_1, ρ_2, ρ_3, respectively, denoting the range measurements from 0, A, B, respectively, to P the substitution of ρ_1, ρ_2, ρ_3, respectively, for R_1, R_2, R_3, respectively, lets one compute the corresponding rectangular coordinates of $\vec{P}$ from (2.7), (2.8), (2.9).

Differentiating in (2.7), (2.8), and (2.9)

$$\dot{x}_1 = \dot{a}a_1^{(1)} + \dot{b}a_1^{(2)} + \dot{c}a_1^{(3)} \quad , \tag{2.10}$$

$$\dot{x}_2 = \dot{a}a_2^{(1)} + \dot{b}a_2^{(2)} + \dot{c}a_2^{(3)} \quad , \tag{2.11}$$

$$\dot{x}_3 = \dot{a}a_3^{(1)} + \dot{b}a_3^{(2)} + \dot{c}a_3^{(3)} \quad , \tag{2.12}$$

where (from differentiating in (2.2), (2.3), and (2.4))

$$\dot{a} = [\dot{\alpha}|\vec{B}|^2 - \dot{\beta}(\vec{A}\cdot\vec{B})]/|\vec{C}|^2 \quad , \tag{2.13}$$

$$\dot{b} = [\dot{\beta}|\vec{A}|^2 - \dot{\alpha}(\vec{A}\cdot\vec{B})]/|\vec{C}|^2 \quad , \tag{2.14}$$

$$\dot{c} = (2R_1\dot{R}_1 - \dot{a}\alpha - \dot{b}\beta - a\dot{\alpha} - b\dot{\beta})/(2c|\vec{C}|) \quad , \tag{2.15}$$

with (from (2.5) and (2.6))

$$\dot{\alpha} = R_1\dot{R}_1 - R_2\dot{R}_2 \quad , \tag{2.16}$$

$$\dot{\beta} = R_1\dot{R}_1 - R_3\dot{R}_3 \quad . \tag{2.17}$$

If in addition to ρ_1, ρ_2, ρ_3 measurements of range rate, $\dot{\rho}_1$, $\dot{\rho}_2$, $\dot{\rho}_3$ are available, (2.10), (2.11), and (2.12) can be used to compute $\dot{x}_1$, $\dot{x}_2$, $\dot{x}_3$. Differentiating again,

$$\ddot{x}_1 = \ddot{a}a_1^{(1)} + \ddot{b}a_1^{(2)} + \ddot{c}a_1^{(3)} \quad , \tag{2.18}$$

$$\ddot{x}_2 = \ddot{a}a_2^{(r)} + \ddot{b}a_2^{(2)} + \ddot{c}a_2^{(3)} \quad , \tag{2.19}$$

$$\ddot{x}_3 = \ddot{a}a_3^{(r)} + \ddot{b}a_3^{(2)} + \ddot{c}a_3^{(3)} \quad , \tag{2.20}$$

where

$$\ddot{a} = [\ddot{\alpha}|\vec{B}|^2 - \ddot{\beta}(\vec{A}\cdot\vec{B})]/|\vec{C}|^2 \quad , \tag{2.21}$$

$$\ddot{b} = [\ddot{\beta}|\vec{A}|^2 - \ddot{\alpha}(\vec{A}\cdot\vec{B})]/|\vec{C}|^2 \quad , \tag{2.22}$$

$$\ddot{c} = \frac{[2(R_1\ddot{R}_1 + \ddot{R}_1^2) - \alpha\ddot{a} - 2\dot{\alpha}\dot{a} - a\ddot{\alpha} - \beta\ddot{b} - 2\dot{b}\dot{\beta} - b\ddot{\beta} - 2\dot{c}^2|\vec{C}|^2]}{2c|\vec{C}|^2} \quad , \tag{2.23}$$

and

$$\ddot{\alpha} = R_1\ddot{R}_1 + \dot{R}_1^2 - R_2\ddot{R}_2 - \dot{R}_2^2 \quad , \tag{2.24}$$

$$\ddot{\beta} = R_1\ddot{R}_1 + \dot{R}_1^2 - R_3\ddot{R}_3 - \dot{R}_3^2 \quad . \tag{2.25}$$

With measurements $\ddot{\rho}_1$, $\ddot{\rho}_2$, $\ddot{\rho}_3$ also available, (2.18), (2.19), and (2.20) can be used to compute $\ddot{x}_1$, $\ddot{x}_2$, $\ddot{x}_3$.

III. GAUSS-NEWTON POINT ESTIMATION - N-STATIONS

In Section II, it was convenient to use the three dimensional vector analysis notation. We now change to a more general notation, leading to a systematic formulation of the Gauss-Newton method for solving the N-station problem.

Let A_i, $i = 1, 2, \ldots, N$, denote the points at which the stations are located and $a_1^{(i)}$, $a_2^{(i)}$, $a_3^{(i)}$, respectively, the first, second, third, respectively, coordinates of A_i with respect to a right-handed coordinate system, so that the coordinate vector of A_i is

$$a^{(i)} = (a_1^{(i)}, a_2^{(i)}, a_3^{(i)})^T \quad .$$

Let

$$x = (x_1, x_2, x_3)^T$$

denote the coordinate vector of P. Let

$$R = (R_1, R_2, \ldots, R_N)^T \quad , \tag{3.1}$$

where the components of R are the ranges from A_i to P, given by

$$R_i = [\sum_{k=1}^{3} (x_k - a_k^{(i)})^2]^{1/2} \quad . \tag{3.2}$$

(Notice that (3.1) and (3.2) give R explicitly as a function of x. We will sometimes use R(x) for this function. Formulas for various derivatives associated with (3.2) are given in Appendix A.)

Three problems in point estimation are posed, and their solution by the Gauss-Newton iteration described. A brief description of the Gauss-Newton iteration is given in Appendix B.

PROBLEM 3.1

Given $\rho = (\rho_1, \rho_2, \ldots, \rho_N)^T$, a vector whose i^{th} component is a (noisy) measurement of the range from A_i to P, find an estimate of x.

PROBLEM 3.2

Given ρ as in Problem 3.1, and $\dot{\rho}$, an N-vector whose i^{th} component is a noisy measurement of the time derivative of the range from A_i to P, find an estimate of x and $\dot{x}$.

PROBLEM 3.3

Given ρ and $\dot{\rho}$ as in Problem 3.2 and $\ddot{\rho}$ an N-vector whose i^{th} component is a noisy measurement of the second time drivative of the range from A_i to P, find an estimate of x, $\dot{x}$, and $\ddot{x}$.

The description in Appendix B of the Gauss-Newton estimate is phrased so as to include these three problems as special cases. For each of the problems we first identify the appropriate vectors of the problem with the vectors m, u, f. The elements of the corresponding F(u) are then obtained from Appendix A and the start vector from Section II.

For Problem 3.1,

$$m = \rho, \; u = x, \; f(u) = R(x) \quad ,$$

and the start vector, $u^{(o)}$ is obtained from (2.7), . . . , (2.9) with R_1, R_2, R_3 replaced by ρ_1, ρ_2, ρ_3 in (2.2), . . . , (2.6).

For Problem 3.2,

$$m = \begin{pmatrix} \rho \\ \dot{\rho} \end{pmatrix} , \quad u = \begin{pmatrix} x \\ \dot{x} \end{pmatrix} , \quad f(u) = \begin{pmatrix} R(x) \\ \dot{R}(x,\dot{x}) \end{pmatrix} ,$$

and the start vector, $u^{(o)}$, is obtained by extending the above start vector by replacing $\dot{R}_1$, $\dot{R}_2$, $\dot{R}_3$ by $\dot{\rho}_1$, $\dot{\rho}_2$, $\dot{\rho}_3$ in (2.13), . . . , (2.17) and computing $\dot{x}^{(o)}$ from (2.10), . . . , (2.12).

For Problem 3.3,

$$m = \begin{pmatrix} \rho \\ \dot{\rho} \\ \ddot{\rho} \end{pmatrix} , \quad u = \begin{pmatrix} x \\ \dot{x} \\ \ddot{x} \end{pmatrix} , \quad f(u) = \begin{pmatrix} R(x) \\ \dot{R}(x, \dot{x}) \\ \ddot{R}(x, \dot{x}, \ddot{x}) \end{pmatrix} ,$$

and the start vector, $u^{(o)}$, is obtained by extending the $u^{(o)}$ of Problem 3.2 by means of Equations (2.18), . . . , (2.25).

It is worth noting that for Problem 3.2, the objective function involves both ρ and $\dot{\rho}$. Hence, $\hat{x}$, the estimate of position for this problem depends on range-rate measurements as well as on range measurements. For Problem 3.3, the objective function involves ρ, $\dot{\rho}$, and $\ddot{\rho}$. In this case, $\hat{x}$ and $\hat{\dot{x}}$, the estimate of position and velocity depends on range, range-rate, and range acceleration measurements. This attribute provides for additional redundancy in the estimation of position in the case of Problem 3.2, and position and velocity for Problem 3.3 that would not be used if position, velocity, and acceleration were estimated sequentially.

IV. RANGE AND RANGE-RATE FILTERING AND DIFFERENTIATION

Measurements of range acceleration are not normally available from the coherent radars at USAWSMR. In order to use the estimation technique described as Problem 3.3 in Section III of this paper, it is necessary to have estimates of range acceleration. This information was derived using a numerical differentiation technique. We chose to do the smoothing and differentiation on the measurements instead of the components of position and velocity to avoid correlation in the error statistics of the data being filtered. It also permits the use of additional redundancy in the point estimation process. The filtering process developed makes use of "a priori" information. In post flight data processing, it is relatively easy to make use of "a priori" information and the improvement in data quality is dramatic. In processing orbital information, the use of "a priori" information is a standard practice. Most of the data generated at USAWSMR is from powered flight or intra-atmospheric free-flight. This makes the use of differential equations of motion for "a priori" information very difficult. Since the process we developed requires that each set of range and range-rate measurements be filtered, the filter process is not optimal but was chosen to provide near optimal filtering that also provides computational efficiency. The process developed during this study is a recursive filter which uses a cubic spline as the predictor. The "a priori" information about the trajectory is introduced as a step function for the third derivative. Integration of this step function is used to derive a predicted trajectory. This prediction is combined with the measured range and range-rate data to provide filtered estimates of range, range-rate, and range acceleration. The filtering process is described as follows.

Let $J_1, J_2, \ldots, J_M$ be the set of M steps of a step function that approximate the third derivative profile of the trajectory under consideration.

Let $T_1, T_2, \ldots, T_M$ be the set of time intervals over which the estimated acceleration rates $J_1, J_2, \ldots, J_M$ are used, respectively.

Let δt be the time interval between data samples.

Let A_o, V_o, and P_o be the initial values of range acceleration, range-rate, and range, respectively. The predicted range acceleration is given by

$$A_k = J_j(\delta t) + A_{k-1} \quad . \tag{4.1}$$

The predicted range-rate is generated using

$$V_k = \frac{[J_j(\delta t)^2]}{2} + A_{k-1}(\delta t) + V_{k-1} \quad . \tag{4.2}$$

The predicted range values are obtained using

$$P_k = \frac{[J_j(\delta t)^3]}{6} + \frac{[A_{k-1}(\delta t)^2]}{2} + V_{k-1}(\delta t) + P_{k-1} \quad , \tag{4.3}$$

where $j = 1, 2, 3, \ldots, M$.

The filter is mechanized to provide estimates of range, range-rate, and range acceleration that are a weighted average of the present measurement and a prediction based on the previous estimate and the acceleration rate profile. The values used for the measured range acceleration are generated using the equation

$$\ddot{R}_k = \frac{(\dot{R}_k - \dot{R}_{k-1})}{(\delta t)} + 0.5J_i(\delta t) \quad . \tag{4.4}$$

The filtered estimates of range, range-rate, and range acceleration are generated using the equations

$$\hat{\ddot{R}}_k = \ddot{R}_k(w_1) + (J_i(\delta t) + \hat{\ddot{R}}_{k-1})(1 - w_1) \quad , \tag{4.5}$$

$$\hat{\dot{R}}_k = \dot{R}_k(w_2) + (\frac{J_i(\delta t)^2}{2} + \hat{\ddot{R}}_{k-1}(\delta t) + \hat{\dot{R}}_{i-1})(1 - w_2) \quad , \tag{4.6}$$

$$\hat{R}_k = R_k(w_3) + (\frac{J_i(\delta t)^3}{6} + \frac{\hat{\ddot{R}}_{k-1}(\delta t)^2}{2} + \hat{\dot{R}}_{k-1}(\delta t) + \hat{R}_{k-1})(1 - w_3) \quad , \tag{4.7}$$

where w_1, w_2, w_3 are weighting values. These weighting values are chosen empirically based on the trajectory being processed. The filtering process just described operates on a series of range and range-rate measurements as a function of time, while the point estimation techniques described in Sections II and III of this paper operate on a collection of measurements from several stations at a single point in time.

V. RANGE AND RANGE-RATE DATA PROCESSING RESULTS

The techniques displayed in this paper were applied to a set of data collected at USAWSMR on 12 September 1973 (Appendix C). The data was collected by three coherent radars tracking a LOKI Sphere. This test provides a very good radar target. An aluminized mylar balloon one meter in diameter is ejected at high altitude. Radar is the only instrumentation available at USAWSMR that can collect data on this target. This limitation makes assessment of data accuracy very difficult.

A segment of data 130 seconds long was processed using the range and range-rate point estimation technique. This data was encoded at 20 samples per second and then averaged to 5 samples per second. No other smoothing was performed on this data. The first 20 seconds of this data contains some errors. It should be noticed that the errors are not propagated along the trajectory using this technique. The remaining 110 second segment of data is free of ambiguities. This 110 second segment was processed using the recursive filter to smooth the range and range-rate data and generate the required range acceleration data. A comparison of the position and velocity data generated by the two processes shows that filtering of the range and range-rate data did not change these results significantly. The acceleration data generated is smooth and represents the kind of accelerations that one might intuitively expect this vehicle to undergo. Visual comparisons with the range user's single radar data reduction indicated good agreement. The following table shows the "a priori" information that was used to obtain the acceleration estimates.

TABLE 5.1 "A PRIORI" ESTIMATES OF RANGE ACCELERATION RATE

Time Interval	Radar 354 $\dddot{R}_1$ (ft/sec^3)	Radar 123 $\dddot{R}_2$ (ft/sec^3)	Radar 352 $\dddot{R}_3$ (ft/sec^3)
20	.573	.720	.492
20	1.746	2.937	4.503
20	-.990	-1.701	-2.178
20	-.513	-.666	-1.023
20	.009	-.063	-.138
10	.120	.126	.018

Notice that the "a priori" information used is simple. Evaluations of this technique that have been performed at USAWSMR indicate that this filter is not particularly sensitive to errors in the "a priori" information. It appears that the coherent radars are capable of producing high quality trajectory data when they are operated as a range and range-rate instrumentation system.

VI. SUMMARY

This paper has presented data processing methods that are applicable to coherent radar when used as a range and range-rate instrumentation system. A technique for smoothing and differentiating range and range-rate data has been presented. This technique permits "a priori" trajectory information to be used easily and with high computational efficiency. A description of point estimation techniques that can be used to obtain rectangular Cartesian components of position, velocity, and acceleration from range and range-rate measurements is included. A description of results obtained from application of the techniques described in this paper to actual flight test data is included. Analysis of the data obtained indicates that coherent radars are a potential source of very good quality trajectory data when used as a range and range-rate instrumentation system.

APPENDIX A

VARIOUS DERIVATIVE FORMULAS

Various derivatives needed in the point estimation problems of Section III are obtained here.

The basic range equation is

$$R_i^2 = \sum_{k=1}^{3} (x_k - a_k^{(i)})^2 \quad . \tag{A.1}$$

Successively differentiating with respect to time,

$$R_i \dot{R}_i = \sum_{k=1}^{3} \dot{x}_k (x_k - a_k^{(i)}) \quad , \tag{A.2}$$

$$\dot{R}_i^2 + R_i \ddot{R}_i = \sum_{k=1}^{3} [\ddot{x}_k (x_k - a_k^{(i)}) + \dot{x}_k^2] \quad . \tag{A.3}$$

Differentiating (A.1) with respect to x_j, $\dot{x}_j$, $\ddot{x}_j$ yields

$$R_i \frac{\partial R_i}{\partial x_j} = \sum_{k=1}^{3} (x_k - a_k^{(i)}) \delta_{kj} = x_j - a_j^{(i)} \quad , \tag{A.4}$$

$$\frac{\partial R_i}{\partial \dot{x}_j} = 0 \quad , \tag{A.5}$$

$$\frac{\partial R_i}{\partial \ddot{x}_j} = 0 \quad . \tag{A.6}$$

Differentiating (A.2) with respect to x_j, $\dot{x}_j$, $\ddot{x}_j$ and using (A.5) and (A.6),

$$\frac{\partial R_i}{\partial x_j} \dot{R}_i + R_i \frac{\partial \dot{R}_i}{\partial x_j} = \dot{x}_j \quad , \tag{A.7}$$

$$R_i \frac{\partial \dot{R}_i}{\partial \dot{x}_j} = x_j - a_k^{(i)} \quad , \tag{A.8}$$

$$\frac{\partial \dot{R}_i}{\partial \ddot{x}_j} = 0 \quad . \tag{A.9}$$

Differentiating (A.3) with respect to x_j, $\dot{x}_j$, $\ddot{x}_j$ and using (A.5), (A.6), and (A.9),

$$2\dot{R}_i \frac{\partial \dot{R}_i}{\partial x_j} + \frac{\partial R_i}{\partial x_j} R_i + R_i \frac{\partial \ddot{R}_i}{\partial x_j} = \ddot{x}_j \quad , \tag{A.10}$$

$$2\dot{R}_i \frac{\partial \dot{R}_i}{\partial \dot{x}_j} + R_i \frac{\partial \ddot{R}_i}{\partial \dot{x}_j} = 2\dot{x}_j \quad , \tag{A.11}$$

$$R_i \frac{\partial \ddot{R}_i}{\partial \ddot{x}_j} = x_j - a_j^{(i)} \quad . \tag{A.12}$$

From (A.1), . . . , (A.12) successively,

$$R_i = [\sum_{k=1}^{3} (x_k - a_k^{(i)})^2]^{1/2} \quad , \tag{A.13}$$

$$\dot{R}_i = \frac{1}{R_i} \sum_{k=1}^{3} \dot{x}_k(x_k - a_k^{(i)}) \quad , \tag{A.14}$$

$$\ddot{R}_i = \frac{1}{R_i} \{\sum_{k=1}^{3} [\ddot{x}_k(x_k - a_k^{(i)}) + \dot{x}_k^2] - \dot{R}_i^2\} \quad , \tag{A.15}$$

$$\frac{\partial R_i}{\partial x_j} = \frac{1}{R_i} (x_j - a_j^{(i)}) \quad , \tag{A.16}$$

$$\frac{\partial R_i}{\partial \dot{x}_j} = 0 \quad , \tag{A.17}$$

$$\frac{\partial R_i}{\partial \ddot{x}_j} = 0 \quad , \tag{A.18}$$

$$\frac{\partial \dot{R}_i}{\partial x_j} = \frac{1}{R_i} (\dot{x}_j - \frac{\partial R_i}{\partial x_j}) \quad , \tag{A.19}$$

$$\frac{\partial \dot{R}_i}{\partial \dot{x}_j} = \frac{1}{R_i} (x_j - a_j^{(i)}) \quad , \tag{A.20}$$

$$\frac{\partial \dot{R}_i}{\partial \ddot{x}_j} = 0 \quad , \tag{A.21}$$

$$\frac{\partial \ddot{R}_i}{\partial x_j} = \frac{1}{R_i} (\ddot{x}_j - 2\dot{R}_i \frac{\partial \dot{R}_i}{\partial x_j} - \frac{\partial R_i}{\partial x_j} \ddot{R}_i) \quad , \tag{A.22}$$

$$\frac{\partial \ddot{R}_i}{\partial \dot{x}_j} = \frac{1}{R_i} (2\dot{x}_j - 2\dot{R}_i \frac{\partial \dot{R}_i}{\partial \dot{x}_j}) \quad , \tag{A.23}$$

$$\frac{\partial \ddot{R}_i}{\partial \ddot{x}_j} = \frac{1}{R_i} (x_j - a_j^{(i)}) \quad . \tag{A.24}$$

From the above formulas, we can form various Jacobian matrices. For example, with $\ddot{R}$ written $\ddot{R}(u) = \ddot{R}(x, \dot{x}, \ddot{x})$, where $u^T = (x^T, \dot{x}^T, \ddot{x}^T)^T$ and $\partial \ddot{R}(u)/\partial \dot{x}$ the N, 3 dimensional matrix whose element in the i^{th} row and j^{th} column is $\partial \ddot{R}_i/\partial \dot{x}_j$, the elements of $\partial \ddot{R}/\partial \dot{x}$ are given by (A.23).

APPENDIX B

GAUSS-NEWTON ITERATION

A Gauss-Newton iteration general enough for the problems of Section III is described without discussion of its limitation.

Let u denote a p, 1 vector of independent real variables and f, or f(u), a vector valued function of dimension q, $p \le q$. Let m denote a q, 1 dimensional constant vector. Consider the equation

$$m = f(u) \quad . \tag{B.1}$$

u is a least squares solution if $\hat{u}$ minimizes the objective function

$$T(u) = ||m - f(u)||^2 = \sum_{i=1}^{q} (m_i - f_i(u))^2 \quad . \tag{B.2}$$

If m is a measurement vector, we will say the $\hat{u}$ is a Gauss estimate of u for the measurement m.

The Gauss-Newton iteration is described as follows.

$$\tilde{T}(u, \delta) \overset{D}{=} ||m - f(u) - F(u)\delta||^2 \quad , \tag{B.3}$$

where F(u) is the q, p dimensional matrix such that the element in the i^{th} row and j^{th} column is

$$\frac{\partial f_i}{\partial u^j}(u) = \frac{\partial f_i(u)}{\partial u^j} \quad .$$

With $u^{(i-1)}$ a given vector, let $\delta^{(i)}$ denote the vector of least norm which minimizes $\tilde{T}(u^{(i-1)}, \delta)$. We consider only the case where

$$\delta^{(i)} = F(u^{(i-1)})^{\dagger}(m - f(u^{(i-1)})) \quad , \tag{B.4}$$

where

$$F(u^{(i-1)})^{\dagger} = [F(u^{(i-1)})^T F(u^{(i-1)})]^{-1} F(u^{(i-1)})^T \quad . \tag{B.5}$$

With $u^{(o)}$ a given start vector, the iteration is

$$\delta^{(i)} = F(u^{(i-1)})^{\div}(m - f(u^{(i-1)}) \quad ,$$

$$u^{(i)} = u^{(i-1)} + \delta^{(i)} \quad , \qquad i = 1, 2, \ldots .$$

If $\{u^{(i)}\}$ converges, say to $\tilde{u}$, we say $\tilde{u}$ is a Gauss-Newton estimate of u for the measurement m. In computation, a way to stop the iteration must be used. With $u^{(r)}$ the last computed iterate we use

$$\hat{u} \approx \tilde{u} \approx u^{(r)} \quad .$$

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   TIME       X(EAST)     Y(NORTH)      Z(UP)       XDOT       YDOT       ZDOT       XDDOT      YDDOT      ZDDOT
 73430.125   -90901.21   253465.36   354951.84    -206.90     980.26   -1979.06     101.04       7.83       9.15
 73430.324   -90951.84   253645.52   354577.77    -203.19     979.52   -1983.41      90.69       6.98       5.28
 73430.524   -91327.74   253781.09   354135.11    -197.99     980.16   -1988.92      83.20       6.54       2.10
 73430.725   -91045.51   254059.39   353754.67    -201.79     978.60   -1995.04      73.46       5.16      -1.08
 73430.925   -91148.91   254242.44   353346.13    -200.54     980.07   -2001.09      66.59       5.39      -3.89
 73431.125   -91293.61   254413.24   352937.18    -198.16     980.87   -2006.88      60.76       4.60      -6.24
 73431.324   -91139.14   254633.12   352571.41    -202.85     980.09   -2013.21      51.88       3.53      -8.78
 73431.524   -91198.47   254843.20   352151.58    -203.34     980.06   -2019.50      47.07       3.32     -10.83
 73431.725   -91268.89   255049.15   351741.77    -199.32     981.16   -2025.22      45.05       3.67     -12.34
 73431.925   -91219.66   255257.33   351350.44    -203.08     980.32   -2031.42      37.61       2.53     -14.18
 73432.125   -91286.52   255458.36   350933.71    -203.68     980.03   -2037.46      34.06       2.23     -15.59
 73432.324   -91315.94   255656.78   350525.70    -203.92     980.38   -2043.54      30.65       2.25     -16.95
 73432.524   -91351.87   255849.98   350118.18    -204.48     980.47   -2049.71      27.27       1.96     -18.23
 73432.725   -91377.49   256047.74   349713.41    -205.06     980.80   -2056.03      24.31       1.93     -19.48
 73432.925   -91435.45   256246.93   349293.59    -205.06     980.71   -2062.22      21.89       1.59     -20.47
 73433.125   -91481.82   256440.90   348879.35    -205.11     980.73   -2068.60      19.66       1.40     -21.53
 73433.324   -91518.24   256633.05   348470.09    -205.83     980.46   -2075.15      17.22       1.01     -22.57
 73433.524   -91568.53   256835.19   348051.16    -205.60     980.23   -2081.35      15.71        .78     -23.22
 73433.725   -91626.43   257029.98   347626.53    -204.92     980.14   -2087.54      14.45        .63     -23.89
 73433.925   -91667.29   257215.45   347213.12    -204.40     980.79   -2093.63      13.23        .94     -24.44
 73434.125   -91685.64   257405.41   346802.73    -205.03     979.64   -2099.84      11.43       -.11     -25.03
 73434.324   -91738.64   257613.52   346371.73    -202.35     979.91   -2105.69      12.04        .30     -25.27
 73434.524   -91759.06   257814.74   345958.44    -205.26     978.93   -2111.87       8.44       -.50     -25.80
 73434.725   -91768.72   258017.50   345544.60    -204.94     979.00   -2117.77       8.41       -.27     -26.03
 73434.925   -91856.46   258197.07   345107.04    -204.52     978.97   -2123.62       7.55       -.35     -26.25
 73435.125   -91898.70   258393.54   344679.29    -204.42     978.75   -2129.40       6.76       -.50     -26.42
 73435.324   -91933.50   258589.75   344256.46    -204.48     978.79   -2135.34       5.99       -.44     -26.69
 73435.524   -91966.67   258781.79   343833.12    -204.62     978.73   -2141.31       5.16       -.51     -26.93
 73435.725   -92016.94   258978.61   343396.46    -204.78     978.61   -2147.20       4.62       -.56     -27.07
 73435.925   -92049.76   259174.19   342971.59    -205.01     978.70   -2153.22       3.99       -.50     -27.31
 73436.125   -92086.59   259372.17   342542.59    -204.78     978.57   -2158.97       3.72       -.60     -27.32
 73436.324   -92137.82   259566.95   342102.55    -204.37     978.41   -2164.78       3.46       -.66     -27.42
 73436.524   -92173.67   259768.24   341667.99    -204.50     978.32   -2170.65       2.92       -.67     -27.53
 73436.725   -92189.54   259961.40   341243.05    -204.64     978.11   -2176.48       2.59       -.80     -27.62
 73436.925   -92259.02   260163.43   340799.37    -204.43     977.98   -2182.28       2.29       -.81     -27.65
 73437.125   -92325.54   260358.39   340353.60    -204.17     977.66   -2188.11       2.07       -.96     -27.71
 73437.324   -92322.31   260547.64   339934.33    -204.56     977.50   -2193.91       1.69      -1.01     -27.78
 73437.524   -92400.07   260738.73   339485.95    -202.03     977.85   -2199.41       3.03       -.70     -27.61
 73437.725   -92426.89   260946.30   339043.18    -203.42     977.07   -2205.34       1.32      -1.24     -27.79
 73437.925   -92459.46   261140.62   338605.92    -202.74     977.12   -2211.11       1.88      -1.00     -27.80
 73438.125   -92485.04   261332.54   338169.87    -202.39     977.00   -2217.02       1.78      -1.07     -27.92
 73438.324   -92545.68   261531.47   337714.64    -201.77     976.97   -2223.10       1.78       -.99     -28.10
 73438.524   -92560.36   261726.46   337276.42    -201.68     977.47   -2229.46       1.61       -.63     -28.45
 73438.725   -92597.08   261909.73   336836.05    -201.55     977.69   -2235.52       1.47       -.61     -28.51
 73438.925   -92656.12   262106.50   336379.43    -201.56     977.90   -2241.66       1.15       -.49     -28.65
 73439.125   -92714.59   262309.24   335923.65    -201.68     977.90   -2247.62        .85       -.51     -28.63
 73439.324   -92727.05   262505.34   335482.76    -202.17     977.81   -2253.35        .53       -.59     -28.53
 73439.524   -92781.43   262701.02   335025.54    -202.05     977.56   -2258.92        .50       -.73     -28.35
 73439.725   -92839.52   262900.55   334567.13    -202.40     977.24   -2264.63        .08       -.87     -28.30
 73439.925   -92837.21   263091.67   334131.20    -202.37     977.10   -2270.07        .29       -.90     -28.10
 73440.125   -92901.47   263291.14   333667.93    -199.89     977.33   -2275.42       1.67       -.67     -27.85
 73440.324   -92944.07   263489.00   333208.59    -201.63     976.52   -2281.14       -.16      -1.23     -27.92
 73440.524   -92984.70   263675.44   332755.31    -201.45     976.31   -2286.65        .28      -1.17     -27.77
 73440.725   -93030.26   263865.88   332298.14    -201.46     976.21   -2292.13        .13      -1.15     -27.66
 73440.925   -93076.23   264068.74   331832.25    -201.30     976.11   -2297.63        .13      -1.11     -27.56
 73441.125   -93105.77   264259.91   331379.10    -201.43     975.83   -2303.01        .00      -1.25     -27.41
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   TIME          X          Y          Z            Ẋ          Ẏ          Ż              Ẍ          Ÿ          Z̈

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  73441.324   -93141.75   264452.41   330719.91    -201.79     975.40    -2308.45        -.26       -1.41     -27.32
  73441.524   -93189.82   264648.47   330454.30    -202.47     974.85    -2314.26        -.71       -1.61     -27.47
  73441.725   -93241.92   264843.43   329985.35    -202.07     974.45    -2320.13        -.34       -1.66     -27.58
  73441.925   -93284.39   265025.57   329528.41    -201.23     974.61    -2326.35         .15       -1.43     -27.92
  73442.125   -93319.42   265235.83   329053.66    -201.69     973.66    -2332.81        -.41       -1.95     -28.28
  73442.324   -93366.14   265418.68   328592.48    -200.96     973.59    -2338.50         .16       -1.74     -28.15
  73442.524   -93385.85   265622.66   328128.18    -201.02     973.57    -2344.44        -.03       -1.61     -28.20
  73442.725   -93423.09   265823.82   327654.03    -200.50     973.97    -2350.01         .25       -1.22     -28.03
  73442.925   -93488.31   266011.31   327181.39    -199.83     973.41    -2355.03         .44       -1.49     -27.57
  73443.125   -93501.10   266208.65   326714.93    -199.98     973.45    -2360.13         .24       -1.42     -27.32
  73443.324   -93544.87   266408.16   326239.70    -200.25     973.11    -2365.31        -.04       -1.52     -27.11
  73443.524   -93581.37   266598.74   325768.54    -199.95     972.63    -2370.36         .19       -1.70     -26.89
  73443.725   -93621.72   266792.39   325294.91    -199.77     972.46    -2375.48         .17       -1.61     -26.65
  73443.925   -93673.90   266994.01   324812.66    -199.22     972.20    -2380.47         .37       -1.62     -26.36
  73444.125   -93724.19   267183.20   324334.02    -198.99     972.33    -2385.61         .32       -1.39     -26.24
  73444.324   -93741.45   267376.85   323864.73    -198.88     972.86    -2391.04         .37       -1.00     -26.35
  73444.524   -93807.61   267578.29   323373.94    -199.19     973.08    -2397.08        -.08        -.88     -26.71
  73444.725   -93831.07   267764.95   322901.96    -200.97     972.81    -2403.27       -1.10       -1.11     -27.10
  73444.925   -93864.80   267950.15   322431.04    -199.60     972.25    -2408.56         .22       -1.41     -26.80
  73445.125   -93923.16   268154.84   321936.57    -199.81     971.38    -2413.96        -.18       -1.74     -26.74
  73445.324   -93952.82   268352.59   321453.09    -200.00     970.73    -2418.92        -.41       -1.89     -26.40
  73445.524   -93989.31   268542.36   320974.09    -200.13     970.33    -2423.94        -.45       -1.93     -26.21
  73445.725   -94048.40   268730.61   320483.18    -200.29     969.58    -2428.92        -.61       -2.21     -26.00
  73445.925   -94074.05   268932.58   319999.23    -200.02     968.71    -2433.53        -.33       -2.46     -25.56
  73446.125   -94126.60   269112.65   319511.11    -200.94     967.45    -2438.85       -1.04       -2.98     -25.73
  73446.324   -94163.29   269321.52   319021.14    -199.65     966.46    -2444.31         .02       -3.13     -25.79
  73446.524   -94195.52   269523.74   318526.41    -200.57     966.11    -2450.54        -.87       -2.91     -26.37
  73446.725   -94229.09   269705.09   318043.18    -199.33     965.94    -2455.53         .23       -2.78     -25.94
  73446.925   -94284.15   269906.66   317546.15    -198.59     966.15    -2460.33         .31       -2.34     -25.63
  73447.125   -94314.93   270092.71   317058.37    -198.74     965.88    -2464.85         .09       -2.42     -25.23
  73447.324   -94330.42   270287.23   316573.40    -198.86     965.84    -2469.56         .07       -2.21     -25.03
  73447.524   -94390.93   270481.21   316072.26    -198.54     965.44    -2473.70         .13       -2.29     -24.41
  73447.725   -94429.23   270675.04   315578.47    -198.65     964.97    -2477.53        -.03       -2.34     -23.78
  73447.925   -94430.50   270864.23   315099.11    -199.16     965.15    -2482.03        -.22       -1.97     -23.73
  73448.128   -94506.97   271059.86   314585.36    -199.42     964.93    -2487.27        -.51       -1.99     -23.99
  73448.324   -94552.74   271253.92   314085.32    -200.14     964.04    -2492.61        -.91       -2.40     -24.19
  73448.524   -94589.84   271443.92   313587.04    -199.49     963.19    -2497.71        -.28       -2.61     -24.19
  73448.726   -94627.27   271627.12   313093.25    -200.54     961.10    -2502.33       -1.08       -3.47     -23.93
  73448.925   -94680.37   271817.31   312586.99    -199.29     959.40    -2506.04        -.07       -3.93     -23.15
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   73478.324  -99164.37  295219.78  241573.36       -75.79     455.54   -1690.25       5.46     -27.53      75.37
   73478.524  -99175.26  295303.69  241247.54       -74.12     449.56   -1674.96       5.76     -27.48      75.11
   73478.725  -99202.94  295391.62  240906.24       -72.53     444.78   -1659.49       5.84     -26.64      75.00
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   73479.125  -99235.39  295572.37  240244.70       -69.33     433.27   -1629.38       6.34     -26.71      74.27
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   73481.125  -99353.26  296381.89  237137.44       -55.41     386.42   -1488.64       6.21     -22.82      68.70
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   73483.125  -99437.67  297119.69  234288.33       -43.97     339.12   -1360.26       5.59     -22.03      62.91
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   73486.725  -99578.09  298193.36  229750.59       -27.14     262.51   -1169.40       5.36     -18.98      49.18
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LOKI SPHERE  12 SEPT  SMOOTHED R AND ROOT                                                DATE 101073       PAGE     9

 73486.925   -99577.23   298253.04   229515.59      -25.00     258.92    -1160.35        6.10     -18.79      48.40
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   73508.925   -99271.90   302084.57   209547.66        19.30      107.58     -774.96          -.11       -5.91        6.40
   73509.125   -99279.63   302105.94   209385.43        19.85      106.63     -773.30           .16       -5.76        6.40
   73509.324   -99275.04   302128.91   209228.59        20.07      105.80     -771.76           .15       -5.56        6.31
   73509.524   -99272.88   302144.36   209078.21        20.11      104.79     -770.20           .10       -5.54        6.26
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    TIME          X            Y            Z              Ẋ          Ẏ          Ż              Ẍ          Ÿ          Z̈

LOKI SPHERE  12 SEPT  SMOOTHED R AND ROOT                                                    DATE 101073      PAGE    11

   73509.725   -99270.39   302162.46   208927.06       20.06     103.67    -768.66         .01      -5.56       6.20
   73509.925   -99256.75   302183.82   208778.01       20.52     102.68    -767.01         .31      -5.46       6.23
   73510.125   -99240.06   302207.78   208618.44       20.89     101.83    -765.45         .38      -5.30       6.17
   73510.324   -99258.15   302226.01   208463.98       21.03     101.08    -764.02         .36      -5.11       6.22
   73510.524   -99250.16   302247.02   208315.59       21.60     100.00    -762.09         .69      -5.17       6.63
   73510.725   -99232.12   302260.55   208176.88       21.42      99.10    -760.69         .43      -5.05       6.53
   73510.926   -99233.12   302277.66   208024.08       21.28      98.01    -759.25         .32      -5.10       6.59
   73511.125   -99234.50   302302.87   207863.90       22.03      96.86    -757.36         .78      -5.14       6.92
   73511.324   -99223.01   302324.59   207713.26       22.24      95.84    -755.85         .71      -5.08       6.88
   73511.524   -99232.63   302349.97   207546.86       22.90      95.04    -754.32        1.01      -4.89       6.94
   73511.725   -99230.43   302366.79   207397.27       23.05      94.05    -752.83         .89      -4.91       6.96
   73511.925   -99229.57   302388.62   207244.15       23.15      92.69    -751.12         .83      -5.13       7.13
   73512.125   -99212.88   302399.79   207106.55       22.96      91.45    -749.75         .64      -5.19       7.01
   73512.324   -99208.70   302418.33   206959.18       23.62      90.34    -748.08        1.04      -5.18       7.18
   73512.524   -99203.59   302431.76   206812.51       24.10      89.21    -746.39        1.14      -5.20       7.28
   73512.725   -99181.09   302455.03   206669.18       24.56      88.28    -744.64        1.26      -5.08       7.41
   73512.925   -99191.92   302469.95   206512.87       24.62      87.28    -743.09        1.06      -5.06       7.41
   73513.125   -99186.87   302489.75   206341.45       24.49      85.94    -741.58         .83      -5.25       7.35
   73513.324   -99189.23   302509.96   206208.78       24.87      84.60    -740.01        1.05      -5.35       7.39
   73513.524   -99183.36   302528.96   206061.02       25.32      83.61    -738.34        1.17      -5.29       7.48
   73513.725   -99181.52   302541.36   205913.77       25.65      82.55    -736.60        1.18      -5.20       7.59
   73513.925   -99177.42   302554.54   205767.67       25.91      81.58    -734.92        1.18      -5.14       7.63
   73514.125   -99168.48   302574.43   205621.23       25.69      80.24    -733.34         .87      -5.33       7.61
   73514.324   -99148.27   302595.96   205478.77       25.57      79.03    -731.69         .77      -5.34       7.66
   73514.524   -99139.10   302610.68   205337.67       25.76      77.68    -729.94         .84      -5.48       7.76
   73514.725   -99140.40   302614.82   205194.45       26.08      76.40    -728.09         .93      -5.63       7.90
   73514.925   -99136.22   302631.07   205048.84       25.99      75.10    -726.25         .71      -5.60       8.00
   73515.125   -99135.65   302650.23   204897.09       26.04      74.01    -724.36         .68      -5.51       8.12
   73515.324   -99144.52   302671.59   204737.84       25.71      72.82    -722.54         .34      -5.63       8.18
   73515.524   -99163.62   302694.66   204569.79       25.55      71.34    -720.80         .22      -5.72       8.19
   73515.725   -99139.45   302703.89   204442.93       25.18      70.02    -719.08         .04      -5.76       8.21
   73515.926   -99098.70   302715.21   204318.57       25.41      68.76    -717.22         .30      -5.79       8.31
   73516.125   -99091.27   302723.38   204187.02       25.05      67.58    -715.42        -.02      -5.76       8.34
   73516.324   -99093.39   302728.49   204045.35       24.62      66.51    -713.65        -.24      -5.67       8.36
   73516.524   -99095.79   302736.07   203903.02       24.36      65.32    -711.88        -.32      -5.69       8.38
   73516.725   -99089.81   302752.70   203760.03       23.88      63.92    -710.08        -.56      -5.83       8.42
   73516.925   -99093.80   302767.16   203609.51       23.48      62.52    -708.38        -.71      -5.90       8.39
   73517.125   -99094.70   302788.22   203458.01       23.62      60.99    -706.52        -.49      -6.06       8.48
   73517.324   -99089.44   302799.38   203319.61       23.12      59.68    -704.96        -.80      -6.04       8.33
   73517.524   -99091.61   302809.32   203173.87       22.63      56.47    -702.96        -.97      -5.99       8.56
   73517.725   -99073.65   302819.80   203040.31       21.90      57.27    -701.23       -1.24      -5.97       8.49
   73517.925   -99093.46   302827.44   202897.00       21.57      55.69    -699.50       -1.26      -6.20       8.48
   73518.125   -99064.51   302856.45   202753.52       21.85      54.03    -697.60        -.87      -6.36       8.58
   73518.324   -99057.18   302845.10   202617.66       22.29      52.65    -695.72        -.58      -6.34       8.63
   73518.524   -99051.34   302861.96   202488.42       21.71      51.20    -693.83        -.93      -6.43       8.69
   73518.725   -99060.22   302866.49   202346.20       21.17      49.69    -691.95       -1.12      -6.58       8.73
   73518.925   -99047.68   302881.65   202210.01       21.01      48.19    -690.03       -1.01      -6.55       8.80
   73519.126   -99047.49   302884.68   202070.98       20.85      46.80    -688.96       -1.00      -6.57       8.61
   73519.324   -99038.54   302900.81   201933.32       20.70      44.93    -686.59        -.98      -6.88       8.72
   73519.524   -99077.17   302904.67   201783.63       20.16      43.39    -685.12       -1.28      -6.88       8.49
   73519.725   -99061.93   302917.39   201645.96       20.26      42.17    -683.18        -.96      -6.71       8.67
   73519.925   -99067.70   302924.31   201505.27       19.76      41.07    -681.61       -1.25      -6.58       8.49
   73520.125   -99033.16   302942.92   201374.94       20.35      39.57    -679.57        -.60      -6.67       8.72
   73520.324   -99022.95   302944.59   201247.32       20.32      38.14    -677.93        -.68      -6.69       8.57
   73520.524   -99010.30   302952.36   201116.00       20.60      36.75    -676.25        -.41      -6.68       8.54
   73520.725   -99004.29   302960.60   200982.49       21.01      35.69    -674.45        -.15      -6.52       8.58
   73520.925   -99015.62   302969.06   200836.73       21.12      34.61    -672.93        -.18      -6.30       8.41
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LOKI SPHERE  12 SEPT  SHOOTHED R AND RDOT                                                 DATE 101073     PAGE    12

   73521.125   -98999.43   302971.40   200714.42      20.64      33.38     -671.49      -.46      -6.32       8.26
   73521.324   -99003.28   302975.71   200576.87      20.69      32.28     -669.99      -.31      -6.18       8.17
   73521.524   -98993.61   302986.39   200440.77      20.69      31.00     -668.51      -.30      -6.21       8.06
   73521.725   -98993.57   302992.41   200306.35      21.03      29.67     -666.93      -.05      -6.23       8.04
   73521.925   -98992.03   303001.71   200167.53      20.98      28.64     -665.53      -.16      -6.04       7.89
   73522.125   -98993.01   303006.41   200030.77      20.79      27.93     -664.02      -.26      -5.72       7.85
   73522.324   -98983.33   303014.60   199903.03      20.42      27.02     -662.48      -.43      -5.62       7.82
   73522.524   -98981.99   303016.09   199770.60      20.41      26.20     -661.18      -.34      -5.43       7.62
   73522.725   -98980.96   303021.92   199635.76      20.60      25.25     -659.67      -.18      -5.36       7.63
   73522.925   -98975.44   303020.95   199506.84      20.63      24.21     -658.36      -.17      -5.34       7.46
   73523.125   -98965.51   303028.75   199380.18      20.70      23.62     -656.96      -.11      -5.00       7.41
   73523.324   -98948.53   303034.16   199256.60      20.42      23.06     -655.51      -.28      -4.76       7.38
   73523.524   -98940.00   303037.87   199129.55      20.21      22.48     -653.95      -.33      -4.56       7.41
   73523.725   -98941.79   303040.21   198995.54      19.85      21.57     -652.68      -.51      -4.60       7.23
   73523.925   -98949.02   303043.83   198857.40      20.27      20.81     -651.20      -.14      -4.45       7.27
   73524.125   -98964.26   303049.95   198715.10      20.51      20.11     -649.94      -.08      -4.33       7.10
   73524.324   -98949.54   303063.45   198580.56      20.11      19.20     -648.67      -.37      -4.35       7.01
   73524.524   -98950.46   303064.54   198450.49      19.94      18.81     -647.42      -.37      -4.00       6.91
   73524.725   -98938.57   303064.29   198329.03      19.77      18.26     -646.13      -.40      -3.90       6.85
   73524.925   -98923.01   303067.58   198212.41      19.42      17.54     -644.98      -.54      -3.88       6.69
   73525.125   -98905.06   303068.79   198094.14      19.68      16.85     -643.77      -.23      -3.80       6.62
   73525.324   -98898.71   303071.45   197966.89      19.69      15.99     -642.57      -.26      -3.86       6.52
   73525.524   -98907.14   303072.15   197833.85      19.94      15.37     -641.30      -.08      -3.72       6.50
   73525.725   -98908.49   303072.24   197703.80      19.80      14.74     -639.96      -.22      -3.64       6.51
   73525.925   -98913.36   303074.00   197570.39      19.69      14.22     -638.76      -.25      -3.50       6.41
   73526.125   -98901.17   303088.29   197437.28      19.60      13.67     -637.52      -.27      -3.39       6.37
   73526.324   -98909.37   303090.87   197302.61      19.94      13.05     -636.18      -.02      -3.35       6.40
   73526.524   -98901.27   303093.51   197178.20      20.25      12.50     -635.05       .14      -3.26       6.26
   73526.725   -98902.47   303092.27   197052.94      20.49      11.88     -633.84       .22      -3.23       6.23
   73526.925   -98892.58   303095.37   196926.21      20.29      11.39     -632.71       .03      -3.11       6.19
   73527.125   -98901.53   303097.64   196791.17      20.33      10.96     -631.41       .07      -2.98       6.18
   73527.324   -98899.15   303098.96   196662.02      20.21      10.30     -630.13      -.02      -3.03       6.17
   73527.524   -98888.22   303095.69   196550.08      20.36       9.93     -628.90       .13      -2.85       6.13
   73527.725   -98874.95   303101.87   196424.36      20.28       9.57     -627.83       .04      -2.72       6.00
   73527.925   -98862.08   303105.12   196304.08      20.67       9.17     -626.66       .32      -2.63       5.98
   73528.125   -98852.23   303104.87   196184.13      20.78       8.81     -625.53       .30      -2.53       5.91
   73528.324   -98860.16   303108.93   196052.88      20.83       8.32     -624.35       .26      -2.51       5.90
   73528.524   -98857.70   303108.76   195924.24      20.09       8.10     -623.11       .27      -2.30       5.92
   73528.725   -98858.11   303108.05   195796.02      21.06       7.92     -621.91       .34      -2.14       5.89
   73528.925   -98869.25   303107.58   195665.75      21.44       7.63     -620.74       .51      -2.06       5.86
   73529.125   -98870.05   303112.57   195537.64      21.93       7.17     -619.40       .71      -2.10       5.94
   73529.324   -98848.88   303119.78   195417.94      22.68       6.86     -618.17      1.08      -1.98       5.92
   73529.524   -98846.35   303116.18   195298.84      22.95       6.54     -617.13      1.01      -1.94       5.79
   73529.725   -98829.45   303114.71   195183.99      23.04       5.96     -615.89       .95      -2.06       5.84
   73529.925   -98825.96   303117.42   195061.39      23.30       6.08     -614.70      1.01      -1.65       5.82
   73530.125   -98815.37   303119.23   194942.09      23.85       5.73     -613.48      1.24      -1.72       5.83
   73530.324   -98809.88   303113.61   194822.88      24.63       5.70     -612.27      1.50      -1.49       5.85
   73530.524   -98772.21   303122.34   194704.87      25.19       5.29     -611.07      1.59      -1.59       5.86
   73530.725   -98643.49   303158.62   194597.23      25.47       4.99     -609.85      1.60      -1.50       5.87
   73530.925   -98597.67   303167.31   194479.32      25.60       4.71     -608.54      1.46      -1.47       5.95
   73531.125   -98586.92   303174.46   194352.88      26.17       4.87     -607.23      1.64      -1.14       6.02
   73531.324   -98578.29   303178.79   194231.97      26.56       4.73     -606.02      1.60      -1.13       5.99
   73531.524   -98561.08   303185.08   194113.85      27.22       4.71     -604.80      1.79       -.98       6.01
   73531.725   -98535.62   303185.11   193997.63      27.86       4.69     -603.60      1.91       -.88       6.00
   73531.925   -98485.08   303198.28   193882.79      28.42       4.66     -602.44      1.99       -.77       5.97
   73532.125   -98507.82   303193.64   193756.20      28.64       4.54     -601.28      1.77       -.76       5.96
   73532.324   -98495.87   303194.08   193637.69      29.00       4.51     -599.94      1.79       -.66       6.07
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   TIME         X           Y           Z             Ẋ          Ẏ         Ż            Ẍ          Ÿ          Z̈
LOKI SPHERE  12 SEPT  SMOOTHED R AND ROOT                                                  DATE 101073      PAGE    13

  73532.524   -98522.39   303185.92   193514.01      29.00       4.64    -598.84       1.48       -.49       5.96
  73532.725   -98532.70   303178.67   193398.49      29.44       4.83    -597.62       1.60       -.33       6.01
  73532.925   -98528.92   303176.64   193282.11      29.78       4.86    -596.48       1.56       -.29       5.96
  73533.125   -98503.10   303185.09   193165.41      30.74       5.13    -595.16       1.98       -.07       6.06
  73533.324   -98474.42   303195.29   193051.84      30.76       5.30    -594.10       1.60        .03       5.93
  73533.524   -98486.29   303200.70   192924.42      30.97       5.37    -592.94       1.63        .07       5.93
  73533.725   -98465.10   303209.87   192798.02      30.77       5.42    -591.92       1.19        .12       5.83
  73533.925   -98487.86   303204.73   192666.41      31.30       5.92    -590.69       1.40        .44       5.90
  73534.125   -98460.73   303211.89   192547.53      32.11       6.34    -589.35       1.70        .62       5.99
  73534.324   -98477.38   303213.38   192418.59      32.71       6.67    -587.91       1.71        .72       6.13
  73534.524   -98482.24   303200.66   192312.36      33.09       6.94    -586.69       1.68        .77       6.09
  73534.725   -98459.70   303196.89   192207.62      32.80       7.28    -585.84       1.25        .90       5.84
  73534.925   -98421.19   303202.53   192107.55      33.10       7.88    -584.53       1.40       1.17       6.00
  73535.125   -98424.77   303194.49   191991.86      33.15       8.17    -583.33       1.19       1.15       5.98
  73535.324   -98422.95   303198.71   191873.23      33.03       8.80    -582.22        .95       1.43       5.92
  73535.524   -98445.12   303198.66   191749.84      33.57       9.43    -580.93       1.19       1.61       6.00
  73535.725   -98468.56   303189.60   191626.53      34.17       9.91    -579.66       1.31       1.67       6.03
  73535.925   -98424.94   303202.46   191510.77      34.21      10.65    -578.51       1.11       1.96       5.98
  73536.125   -98368.04   303225.48   191398.03      34.02      10.63    -577.17        .88       1.65       6.09
  73536.324   -98479.51   303208.19   191263.08      34.02      11.01    -575.91        .67       1.75       6.09
  73536.524   -98460.16   303211.94   191153.48      34.26      11.36    -574.59        .78       1.77       6.15
  73536.725   -98452.10   303212.07   191042.47      34.83      11.88    -573.28       1.01       1.90       6.19
  73536.925   -98424.65   303223.55   190930.67      35.07      12.16    -571.97        .95       1.83       6.22
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  73537.324   -98351.65   303237.15   190711.72      34.63      12.09    -569.49        .50       1.45       6.21
  73537.524   -98389.12   303226.72   190589.71      35.10      12.19    -568.07        .72       1.41       6.33
  73537.725   -98362.48   303230.91   190478.29      35.57      12.27    -566.75        .87       1.33       6.33
  73537.925   -98336.04   303236.87   190368.96      35.82      12.35    -565.60        .86       1.27       6.24
  73538.125   -98348.33   303235.30   190253.59      36.08      12.34    -564.46        .85       1.13       6.19
  73538.324   -98364.77   303239.23   190132.54      36.57      12.44    -563.23        .99       1.12       6.20
  73538.524   -98271.12   303257.35   190039.03      36.54      12.12    -561.82        .85        .81       6.32
  73538.725   -98318.24   303243.26   189920.58      36.89      12.29    -560.61        .91        .92       6.26
  73538.925   -98350.86   303239.99   189798.02      36.52      12.00    -559.56        .49        .62       6.13
  73539.125   -98325.00   303246.27   189686.31      36.77      11.95    -558.29        .64        .61       6.19
  73539.324   -98276.02   303261.82   189581.06      36.84      11.88    -557.15        .58        .55       6.11
  73539.524   -98283.45   303259.15   189467.08      36.94      11.83    -555.97        .52        .48       6.10
  73539.725   -98286.41   303257.79   189356.97      36.81      11.59    -554.79        .34        .31       6.09
  73539.925   -98259.79   303259.00   189254.86      36.99      11.43    -553.57        .45        .24       6.09
  73540.125   -98253.13   303257.33   189145.23      36.80      11.21    -552.37        .21        .11       6.08
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  TIME        X(EAST)      Y(NORTH)       Z(UP)         XDOT        YDOT        ZDOT
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 73410.324   -86679.364   234053.828   388133.703    -215.842     982.267   -1370.590
 73410.524   -86692.846   234244.781   387869.184    -215.822     982.338   -1376.944
 73410.725   -86718.579   234436.328   387595.078    -216.054     982.410   -1383.360
 73410.925   -86818.178   234634.898   387307.062    -215.731     982.438   -1389.732
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    73449.324     -94778.216     272214.578     311576.637       -197.026        957.945       -2515.236
    73449.524     -94775.687     272399.625     311088.426       -197.543        956.858       -2520.066
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    73455.324     -95897.100     277886.465     296150.598       -188.067        925.130       -2614.567
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LOKI SPHERE  12 SEPT  SHOOTHED H AND ROOT                                       DATE 10In73         PAGE    20

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     73487.725     -99610.030     298460.129     228585.150        -19.142       245.879     -1126.701
     73487.925     -99620.716     298493.738     228368.068        -17.094       242.665     -1118.196
     73488.125     -99596.943     298541.316     228160.367        -16.050       239.734     -1110.184
     73488.324     -99584.280     298590.379     227952.090        -15.075       237.470     -1102.284
     73488.524     -99592.626     298640.750     227727.617        -13.828       235.150     -1094.534
     73488.725     -99607.799     298694.453     227495.596        -12.327       232.454     -1087.075
     73488.925     -99626.853     298737.004     227272.473        -10.755       229.596     -1079.711
     73489.125     -99621.994     298780.922     227062.982        -10.276       227.324     -1072.550
     73489.324     -99633.994     298817.945     226847.314         -9.193       225.061     -1065.394
     73489.524     -99626.107     298866.844     226636.107         -7.437       223.074     -1058.426
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    TIME            X               Y               Z                 Ẋ               Ẏ              Ż
LOKI SPHERE  12 SEPT  SMOOTHED R AND RDOT                                           DATE 101073        PAGE   23

    73489.725    -99624.255      298913.344      226427.824        -6.404         220.676       -1051.453
    73489.925    -99616.758      298960.845      226221.793        -4.646         218.301       -1045.048
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    73491.925    -99622.673      299378.758      224184.973         9.688         202.199        -986.646
    73492.125    -99652.845      299420.953      223979.160         6.736         199.681        -981.918
    73492.324    -99648.029      299459.867      223781.453        10.423         199.276        -976.458
    73492.524    -99678.683      299490.004      223583.437        12.439         198.643        -970.958
    73492.725    -99624.313      299535.715      223403.629        12.314         197.650        -966.226
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    73497.925    -99485.817      300517.156      218635.947        23.313         175.329        -884.018
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    73498.324    -99506.465      300590.535      218264.082        23.460         172.814        -878.732
    73498.524    -99493.646      300623.184      218092.794        23.711         171.384        -876.179
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     TIME          X            Y             Z             Ẋ            Ẏ             Ż
LOKI SPHERE  12 SEPT  SHOOTHED R AND ROOT                                 DATE 101n73        PAGE    24

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TIME	X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$
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73523.725	-98942.829	303039.844	198994.953	19.754	21.543	-652.752

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LOKI SPHERE  12 SEPT  SMOOTHED R AND RDOT                                          DATE 101073      PAGE    26

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        73528.524    -98857.992     303108.453     195923.561          20.888           8.193        -623.090
        73528.725    -98858.912     303107.645     195795.361          21.095           8.007        -621.904
        73528.925    -98871.969     303107.223     195664.691          21.540           7.683        -620.738
        73529.125    -98870.942     303113.195     195536.922          22.052           7.148        -619.349
        73529.324    -98845.934     303120.805     195418.650          22.894           6.902        -618.156
        73529.524    -98845.528     303115.305     195299.623          22.964           6.565        -617.175
        73529.725    -98827.459     303114.227     195185.479          23.015           5.887        -615.864
        73529.925    -98826.145     303117.699     195061.479          23.327           6.254        -614.695
        73530.125    -98814.314     303119.355     194942.715          23.971           5.721        -613.466
        73530.324    -98809.769     303112.422     194823.482          24.804           5.806        -612.258
        73530.524    -98766.428     303123.680     194705.629          25.282           5.257        -611.058
        73530.725    -98621.666     303164.840     194599.777          25.483           5.007        -609.841
        73530.925    -98590.509     303168.672     194480.016          25.546           4.716        -608.501
        73531.125    -98585.916     303175.574     194352.021          26.268           5.023        -607.184
        73531.324    -98677.715     303179.383     194232.041          26.586           4.762        -606.026
        73531.524    -98558.973     303186.035     194114.373          27.330           4.783        -604.798
        73531.725    -98532.088     303184.961     193998.443          27.963           4.744        -603.600
        73531.925    -98477.156     303200.441     193883.809          28.492           4.715        -602.459
        73532.125    -98512.841     303192.668     193755.100          28.575           4.554        -601.295
        73532.324    -98494.777     303194.008     193637.977          29.009           4.550        -599.884
        73532.524    -98528.100     303184.328     193513.330          28.876           4.724        -598.884
        73532.725    -98535.550     303177.227     193399.221          29.485           4.924        -597.603
        73532.925    -98529.301     303176.113     193282.639          29.788           4.894        -596.503
        73533.125    -98499.608     303186.410     193165.852          30.966           5.234        -595.112
        73533.324    -98470.447     303196.902     193052.779          30.636           5.364        -594.152
        73533.524    -98489.483     303201.473     192922.887          30.930           5.388        -592.953
        73533.725    -98462.482     303211.289     192796.615          30.607           5.439        -591.980
        73533.925    -98492.978     303203.629     192664.055          31.388           6.075        -590.671
        73534.125    -98457.043     303212.949     192547.379          32.289           6.454        -589.302
        73534.324    -98481.465     303213.914     192416.617          32.785           6.742        -587.827
        73534.524    -98484.271     303198.168     192314.340          33.113           6.970        -586.689
        73534.725    -98456.899     303195.973     192209.826          32.599           7.343        -585.963
        73534.925    -98415.570     303203.262     192110.543          33.134           8.024        -584.485
        73535.125    -98426.572     303192.793     191992.049          33.072           8.181        -583.331
```

```
      TIME           X              Y              Z                  Ẋ               Ẏ              Ż
LOKI SPHERE  12 SEPT  SMOOTHED R AND RDOT                                          DATE 101073       PAGE    27

      73535.324     -98423.809     303199.168     191872.863         32.909           8.928        -582.250
      73535.524     -98450.205     303198.344     191748.598         33.685           9.543        -580.894
      73535.725     -98473.871     303187.660     191625.250         34.289           9.957        -579.642
      73535.925     -98418.453     303204.371     191510.773         34.139          10.787        -578.528
      73536.125     -98359.215     303229.152     191398.529         33.898          10.495        -577.119
      73536.324     -98500.380     303204.766     191259.604         33.936          11.015        -575.899
      73536.524     -98457.964     303212.203     191154.441         34.305          11.357        -574.559
      73536.725     -98451.882     303211.691     191043.143         34.974          11.941        -573.255
      73536.925     -98421.033     303225.148     190931.154         35.090          12.129        -571.942
      73537.125     -98388.988     303234.703     190821.521         34.705          12.046        -570.767
      73537.324     -98345.535     303237.375     190712.605         34.526          11.953        -569.485
      73537.524     -98396.942     303224.453     190588.258         35.221          12.126        -568.004
      73537.725     -98359.018     303231.219     190478.648         35.679          12.207        -566.734
      73537.925     -98332.620     303237.496     190369.650         35.850          12.290        -565.644
      73538.125     -98351.777     303234.586     190253.166         36.104          12.244        -564.495
      73538.324     -98368.924     303239.484     190131.080         34.669          12.401        -563.237
      73538.524     -98255.905     303260.105     190042.383         34.482          11.937        -561.765
      73538.725     -98327.863     303240.344     189919.482         36.941          12.291        -560.621
      73538.925     -98357.931     303238.977     189796.152         36.322          11.845        -559.624
      73539.125     -98321.729     303246.949     189686.332         36.825          11.893        -558.273
      73539.324     -98268.687     303264.137     189582.160         36.836          11.821        -557.188
      73539.524     -98286.060     303258.262     189466.617         36.925          11.771        -555.987
      73539.725     -98288.252     303257.129     189357.139         36.731          11.478        -554.798
      73539.925     -98256.388     303258.805     189256.404         37.031          11.355        -553.571
      73540.125     -98253.257     303256.641     189145.400         36.713          11.114        -552.382
```

APPENDIX B

EVALUATION OF RANGE-RATE DATA

BY

BALL CHIN
Electronics Division

Instrumentation Directorate
US Army White Sands Missile Range, New Mexico 88002

PRELIMINARY RESULTS OF WSMR PULSE DOPPLER RADARS TRACKING TESTS

WSMR PULSE DOPPLER RADARS

- OPERATIONAL
    - THREE FPS-16(AX) RADARS
    - THREE MPS-36 RADARS
- OTHER
    - THREE MPS-36 RADARS (OPERATIONAL IN 90 DAYS)

OBJECTIVES

- ESTABLISH PULSE DOPPLER RADARS TRACKING CAPABILITY
- DETERMINE IMPROVEMENTS REQUIRED FOR PRECISE AND RELIABLE VELOCITY DATA
- INTEGRATE VELOCITY DATA WITH RANGE DATA TO PROVIDE FOR
    - REAL-TIME EVENTS AND POSITION DETERMINATION
    - FLIGHT SAFETY IMPACT PREDICTION
    - MORE PRECISE POST FLIGHT TRAJECTORY ANALYSIS

TEST RESULTS

- A-4 AIRCRAFT TRACKING TEST, 14 DECEMBER 1973

RADAR	R113	R123	R127	R352	R354	R393
RELIABILITY DOP VEL WHEN TARGET IS RECEDING (%)	99.1	99.4	97.8	96.1	97.7	93.4
RELIABILITY DOP VEL WHEN TARGET IS APPROACHING (%)	99.5	81.5	78.9	91.4	94.2	78.6
RADAR RANGE TRACKING RELIABILITY (%)	99.7	100.0	99.8	100.0	99.9	100.0
RELIABILITY OF R DOT DATA (%)	95.4	92.2	88.7	94.1	96.2	87.3

- SPHERE DROP TEST, 16 FEBRUARY 1974

  RELIABILITY OF ALL SIX RADARS WAS BELOW 40 PERCENT

OTHER ACCOMPLISHMENTS

- COMPUTER PROGRAM TO PROCESS DOPPLER DATA FROM REAL TIME FIELD TAPES IN 24 HOURS (REFER TO INTERNAL MEMO 148)
- FLOW CHART FOR MPS-36 DOPPLER COMPUTER PROGRAM

Future Plans

- Examine and Verify Alignment, Calibration, and Premission Checkout Procedures
- Conduct System Analysis, Including Transponder and Airborne Antenna Radiation Pattern and Target Dynamics Prior to Each Test
- Participate in Geos-C Satellite Tracking Tests

Source of Additional Information

- Dr. Robert H. Paul, Technical Director
  Instrumentation Directorate
  White Sands Missile Range
  New Mexico 88002

INTERNAL MEMORANDUM NUMBER 148

DESCRIPTION AND USERS MANUAL
FOR THE
NR-AM-I KRTLST COMPUTER PROGRAM

FEBRUARY 1974

Prepared by Otto Paul Kroeger Jr.
O. P. Kroeger
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APPENDIXES

DESCRIPTION AND USERS MANUAL
FOR THE NR-AM-I KRTLST COMPUTER PROGRAM

I. ABSTRACT. The KRTLST computer program dumps and analyses radar range rate data recorded at the real-time facility. It is a very simple program to operate and requires no programming experience to use it. Anyone who has a legitimate computer project accounting number (PAN) can schedule runs at the WSMR 1108 Computer B Facility.

II. INTRODUCTION. The KRTLST computer program was written by O. P. Kroeger (Instrumentation Integration Section) as part of an inter-organizational task effort by Analysis and Computation Division, Data Collection Division and Instrumentation Directorate to evaluate the existing WSMR radar range rate system.

The KRTLST program uses as inputs the data recorded in real-time at the Real Time Systems Section's computer facility in Bldg 300. These inputs are data gathered by radars.transmitted from the radar site via Lenkurt modems and recorded on analog tape recorded all in real-time. Either in real-time (or in deferred time by analog tape playbacks) digital log tapes of the mission data are generated on the WSMR 1108 real-time computer. The KRTLST program cannot be used unless this real-time recording has been range scheduled and accomplished.

The KRTLST program outputs setup cards for checks, radar data samples of time, range, azimuth, elevation, range rate, computed estimates of range rate from range derivatives, differences of range rate and range derivatives, acceleration, data one sigma error estimates, and flags of various predetermined errors. At the end of the data listing an automated written consolidated report of error and reliability statistics is furnished.

III. DESCRIPTION OF ALL STEPS NECESSARY TO ACCOMPLISH KRTLST OUTPUTS.

STEP NR 1. Prior to mission, range schedule a real time recording of all radars supporting the mission. Real-time recordings are only made on missions which have been scheduled specifically as "real-time transmission and record".

STEP NR 2. Obtain the mission code (FC = Foxtrot Charley, AB = Alpha Bravo, etc.), mission date, and mission start and stop times if available.

Obtain "PSL Real Time Playback Request" cards from PSL Input Office, Bldg 300. Fill out request card (see Fig (1A)) with:

1. Requestor - your name.
2. Acct Code - your accounting code.
3. Mission - put in mission code.
4. Program - put in "UNILOG"
5. Date - put in the mission firing date.
6. Phone - your duty phone
7. Building - put in X in the 300 block.
8. Timing - put an X in the range block.
9. Remarks - put "log all radars" plus mission start time and mission stop time if available.
10. Bottom Line - put an X in the deliver box along with your name and nearest PSL delivery point.

FIGURE (1A) shows my request for an 1108 computer log tape of an aircraft track mission fired on 14 Dec 73. The mission was Charley Foxtrot (FC).

FIGURE (1B) shows my request card after the logging procedure was accomplished. PSL operations filled in the following:

1. Analog reel block.
2. Tape classification block.
3. Tape location block.
4. Tape reel number block.
5. Marked the ID's of the radars available in the input blocks and their associated computer sub-channels.

FIGURE (1B) shows that radar R113, R123, R127, R352, R354 and R373 were recorded and the input tape for the KRTLST is labeled W385/42703. With this information we are ready to set up the deck for a KRTLST computer run.

STEP NR 3. The KRTLST run deck consists of seven punched IBM cards and one request card. (See FIGURE (2)) Only two cards have to be punched for each run. The others remain constant. The two cards to be punched are:

1. Card Nr 1 - Punch the input data tape location in columns 16, 17, 18, 19. Punch the input data tape reel number in columns 28, 29, 30, 31, 32. For example, FIGURE (3) shows data punch for Card Nr 1 for the aircraft mission designated on the playback request card shown in FIGURE (2B). (W385/42703)

2. Card Nr 6 - The data card is the most complicated and is used to control the radar to be dumped, the portions of the run to be dumped, and the long or short print control options. (See FIGURE (4))

Columns 1 to 4 are the easiest. They simply contain the name of the radar to be dumped. The only allowable characters for the dump are:

Columns	1	2	3	4
	R	1	1	3
	R	1	2	3
	R	1	2	7
	R	3	5	4
	R	3	5	2
	R	3	9	3
	R	3	5	0
	R	3	5	1

Columns 11 to 20 contain the range time of the desired start time of the run. (Three decimals) (Example: 67350.000)

Columns 21 to 30 contain the range time of the desired stop time of the run. (Three decimals) (Example: 68650.000)

Columns 59 and 60 are an index to be used with Columns 67, 68, 69 and 70 to control specific segments of the trajectory to be dumped such as first, second, third -- ninety-ninth segment.

Columns 67, 68, 69 and 70 contain a time segment of seconds (0000 to 9999) to be dumped. (Always use in conjunction with Columns 59 and 60. For example, if column 60 had a "3" in it and Columns 68, 69 and 70 had 100 in them, the program would print only the third 100 seconds of data on the tape. If Columns 59 and 60 and 67, 68, 69 and 70 are used then the start time (Columns 11 to 20) and the stop time (Columns 21 to 30) should be blank. (And vice-versa.)

If none of the print time controls are used i.e. Columns 11 to 20, 21 to 20, 59, 60, 67 to 70 are all blank, then all data on the log tape will be processed.

Column 80 controls short or long print. If Column 80 is "1", only error flagged data and check prints every five seconds on good data are printed. If Column 80 is "0" every processed sample (20 samples/second) is printed.

EXAMPLES

Figure (5A). Shows data card which instructs the program to dump all data on the input tape for radar R113. (Long print)

Figure (5B). Shows data card which instructs the program to dump all data between times 67350.000 to 68650.000 seconds of the mission for radar R113. (Long print)

Figure (5C). Shows data card which instructs the program to dump error flagged data (short print) during the third 200 seconds of data recorded on the tape.

STEP NR 4. The run request card is depicted in Figure (6). As can be seen, there are three major blocks to be filled out: input, output and identification. (Be sure and correctly label all classification blocks. If they are not labeled, PSL will not make the run. Do not use classified input tapes for this dump program because the outputs of the of the program will become classified. As a rule run only data from unclassified projects.

In the input tape block two tapes have to be entered. The program tape is always E725/39027 until after Feb 74. Call Kroeger (678-1620) for new program tape designations and at four month intervals after that. The second tape will be the input data log tape you have requested from the PSL Real Time Playback Facility. The number of cards will always be seven.

In the output section (under PRINT$) always put NØRM unless you have changed the deck to get one or more carbons.

In the identification block check R under option block, fill in your RUN ID, PAN, requestor's name, phone, organization, check Computer B, put your delivery destination point. The time estimate and page estimate is computed as follows:

TIMING ESTIMATE

1. Four minutes for first 0 to 200 seconds of flight.
2. Add 1.1 minutes for each additional 50 seconds of flight.
3. Round fractional times up when equal to .5 seconds and greater.

EXAMPLE NR 1 - For a 556 second flight.

$$\left.\begin{array}{rl} 556 & \text{sec} \\ \underline{200} & \text{- first seg} \end{array}\right\} \text{4 min}$$

$$\begin{array}{r} 356 \\ 7 \\ 50\overline{)356} \\ \underline{350} \end{array} \qquad 7 * 1.1 = 7.7 = 8$$

TOTAL TIME = 12 MIN

EXAMPLE NR 2 - For a 320 second flight.

$$\left.\begin{array}{r} 320 \\ \underline{200} \end{array}\right\} \text{4 min}$$

$$\begin{array}{r} 120 \\ 2 \\ 50\overline{)120} \end{array} \qquad 2 \times 1.1 = 2.2 = 2 \text{ min}$$

TOTAL TIME = 6 MIN

EXAMPLE NR 3 - For a 1298 second flight.

```
      1298              } 4 min
       200
      1098
        21
   50 |1098             21 * 1.1 = 23.2 = 23
      100
        98
   TIME = 4 + 23 = 27 MIN
```

PAGES OF PRINT ESTIMATE

Ten pages plus one page for every 2.5 seconds of flight data.

EXAMPLE - For 1300 seconds flight.

```
   10  pages                  520
  520                   2.5 |13000
  530
```

530 PAGES

IV. INTERPRETATION OF OUTPUT LISTING. The output listing has four parts. The first part is a three page computer summary of loading parameters which includes the tape assignments for checks. The second part is a one page listing printed by the program giving the data card setup and the error code definitions. The third part (the longest) is the listing of the data as follows (left to right)

1. Radar name or the error code if an error has been detected. The following list gives error code definitions.

E100000) = DOPPLER DVES VALID FLAG HAS CHANGED.

E 20000) = DOPPLER 21PT RAW DATA SIGMA HAS CHANGED.

E 3000) = VELOCITY EEOR G.T. 14.31 F.P.S.

E 400) = TIME HAS A GAP (NOT .05 SEC)DERIVATIVES BAD.

E 50) = RADAR HAS CHANGED ITS TRACK MODE.

E 6) = NOT PRESENTLY ASSIGNED.

E 20050) = ERRORS 2 AND 5 BOTH PRESENT (EXAMPLE).

2. Time - seconds.

3. Time difference - seconds for missing data checks. (This may be changed later to display AGC.

4. Radar track mode:

S = skin track
B = beacon track
N = no track

5. DVES valid flag:

1 = valid flag yes
0 = valid flag no

6. Doppler skin return flag:

1 = yes
0 = no

7. Doppler COHO beacon flag:

1 = yes
0 = no

8. Range - feet.

9. Azimuth - degrees.

10. Elevation - degrees.

11. Second derivative of range (acceleration) 51 pt filter ft/sec^2.

12. Doppler velocity derivative (acceleration 51 pt filter ft/sec^2.

13. Range first derivative (velocity) one sigma error estimate ft/sec. (21 pt filter)

14. Raw doppler velocity error estimate (21 pt filter) ft/sec.

15. First derivative of range (velocity) 21 pt filter ft/sec.

16. Raw doppler velocity ft/sec.

17. Velocity error (difference between raw doppler velocity and 51 pt range derivative) ft/sec.

18. Velocity error (difference between raw doppler velocity and 21 pt range derivative) ft/sec.

The long print (data card COL 80-0) gives the above information for each and every point. (20 SAM.SEC.)

The short print (data card COL 80=1) prints only flagged errors (see 1. above) <u>plus</u> 24 consecutive samples prior to a flagged error and 24 consecutive samples past the same flagged error. Also, during long stretches of good data, a checkpoint will be printed every five seconds.

The fourth part of the listing is a written statistical report of the entire run. The basic criteria for most percentages and reliability estimates are based on the premise that when the radar is in track (either skin or beacon), there should be valid unambiguous velocity data (with valid vel flags). The run printout will not commence until the radar has been in solid track for at least two seconds. The radar reliability number is based on outages versus skin or beacon track once the run has begun.

If the computer run aborts, check the last page of your listing for such things as tape problems, max time, max pages. If either max time or pages is indicated, your estimates on your run request card are wrong and should be increased.

V. <u>PROGRAM LISTING</u>. For those who wish to know what the program KRTLST coding looks like, a listing of the program is included.

For those who wish to have deck of the program for their own purposes may easily do so. The Fortran elements are on the program input tape. To punch (on line) the deck during a run place the following cards directly after the copin card in the data deck:

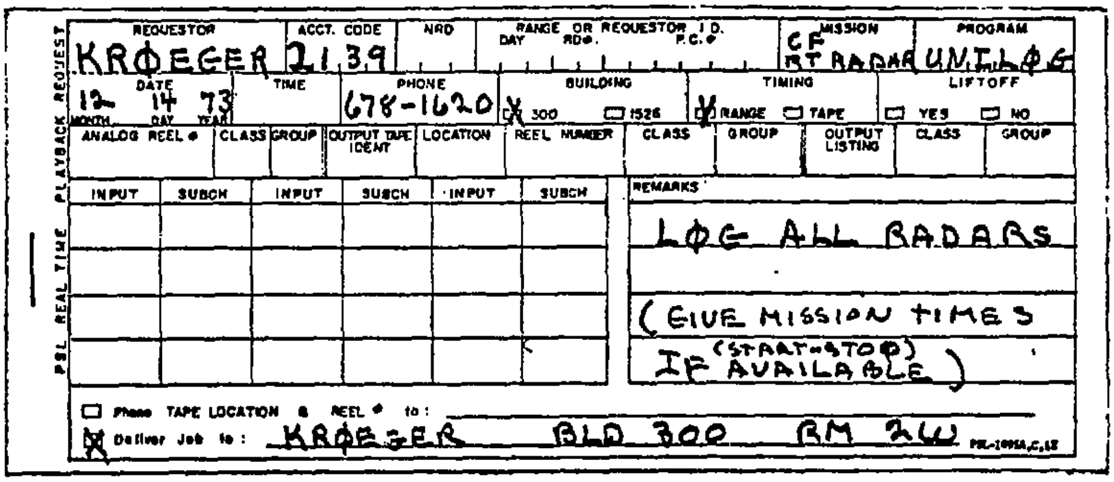
```
1.  @PCH,SC     TPF$.ROYSA

2.  @PCH,SC     TPF$.ROYSO

3.  @PCH,SC     TPF$.LOG
    ↑           ↑
    COL 1       COL 14
```

APPENDIX A

REAL TIME PLAYBACK REQUEST CARDS



PSL REAL TIME PLAYBACK REQUEST

REQUESTOR	ACCT. CODE	NRD	RANGE OR REQUESTOR I.D. DAY RD# P.C.#	MISSION	PROGRAM
KRØEGER	2139			CF RT RADAR	UNILØG

DATE MONTH DAY YEAR	TIME	PHONE	BUILDING	TIMING	LIFTOFF
12 14 73		678-1620	☒ 300 ☐ 1526	☒ RANGE ☐ TAPE	☐ YES ☐ NO

ANALOG REEL #	CLASS	GROUP	OUTPUT TAPE IDENT	LOCATION	REEL NUMBER	CLASS	GROUP	OUTPUT LISTING	CLASS	GROUP

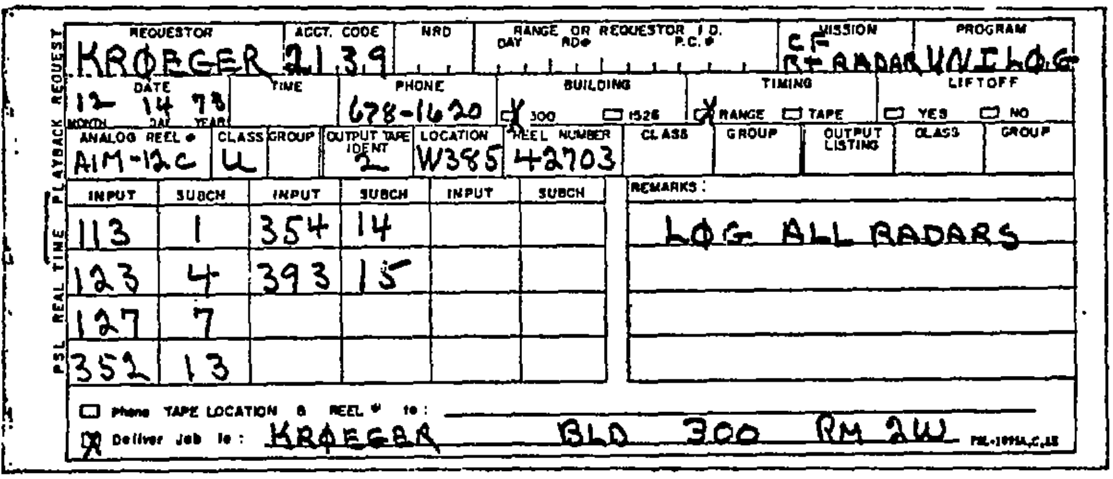
INPUT	SUBCH	INPUT	SUBCH	INPUT	SUBCH

REMARKS:
LØG ALL RADARS
(GIVE MISSION TIMES
IF (START-STOP) AVAILABLE)

☐ Phone TAPE LOCATION & REEL # to:
☒ Deliver Job to: KRØEGER BLD 300 RM 2W

PSL-1095A,C,LS

FIGURE (1A)



PSL REAL TIME PLAYBACK REQUEST

REQUESTOR	ACCT. CODE	NRD	RANGE OR REQUESTOR I.D. DAY RD# P.C.#	MISSION	PROGRAM
KRØEGER	2139			CF RT RADAR	UNILØG

DATE MONTH DAY YEAR	TIME	PHONE	BUILDING	TIMING	LIFTOFF
12 14 73		678-1620	☒ 300 ☐ 1526	☒ RANGE ☐ TAPE	☐ YES ☐ NO

ANALOG REEL #	CLASS	GROUP	OUTPUT TAPE IDENT	LOCATION	REEL NUMBER	CLASS	GROUP	OUTPUT LISTING	CLASS	GROUP
AIM-12C	U		2	W385	42703					

INPUT	SUBCH	INPUT	SUBCH	INPUT	SUBCH
113	1	354	14		
123	4	393	15		
127	7				
352	13				

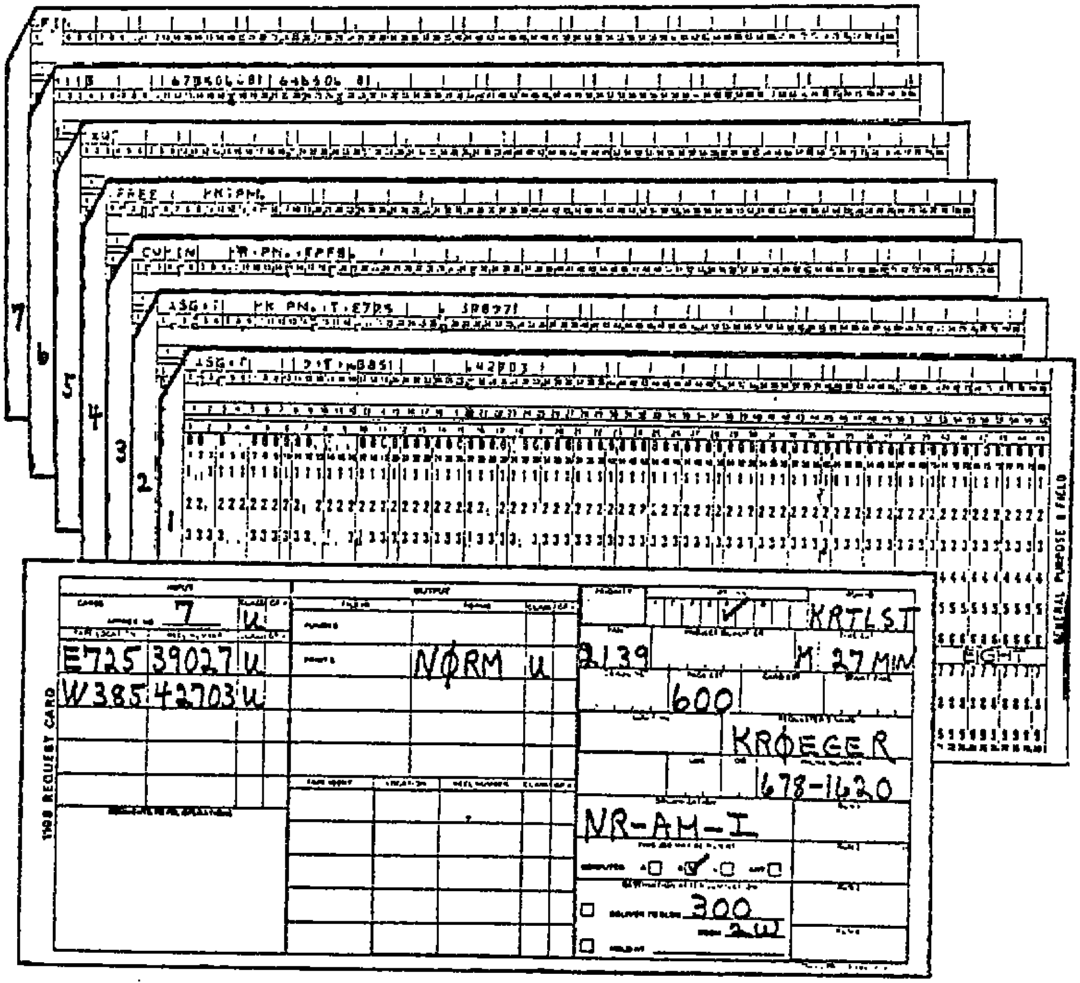
REMARKS:
LØG ALL RADARS

☐ Phone TAPE LOCATION & REEL # to:
☒ Deliver Job to: KRØEGER BLD 300 RM 2W

PSL-1095A,C,LS

FIGURE (1B)

SAMPLE DECK AND REQUEST CARD



1108 REQUEST CARD

INPUT

OUTPUT

7 U

E725 39027 U

W385 42703 U

NORM U

KRTLST

2139

M 27 MIN

600

KROEGER

678-1620

NR-AM-I

☐ 300

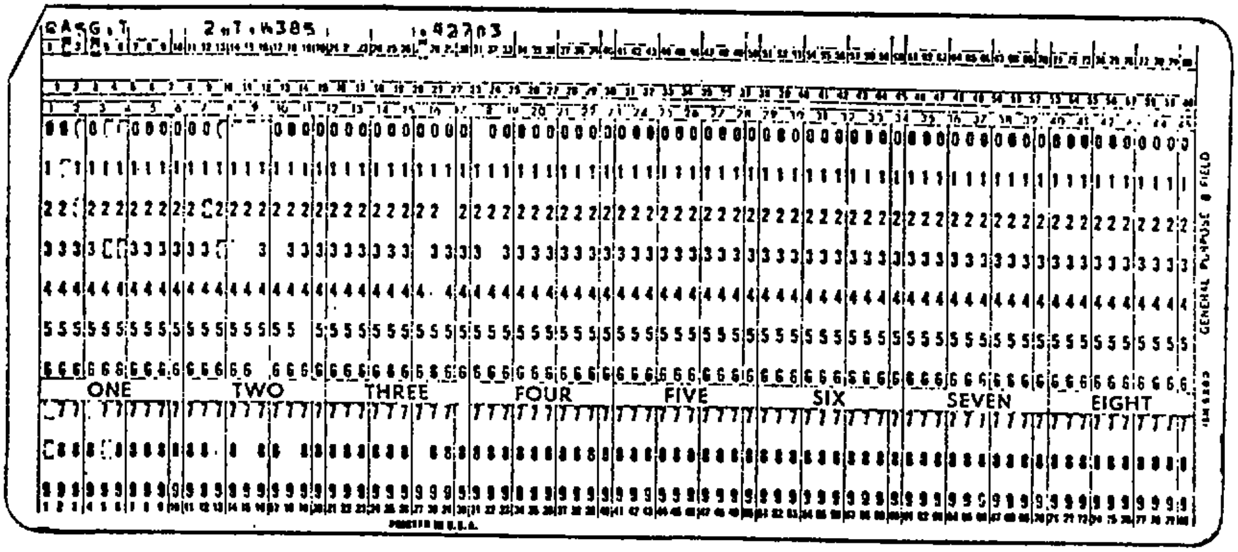
2 W

☐

FIGURE (2)

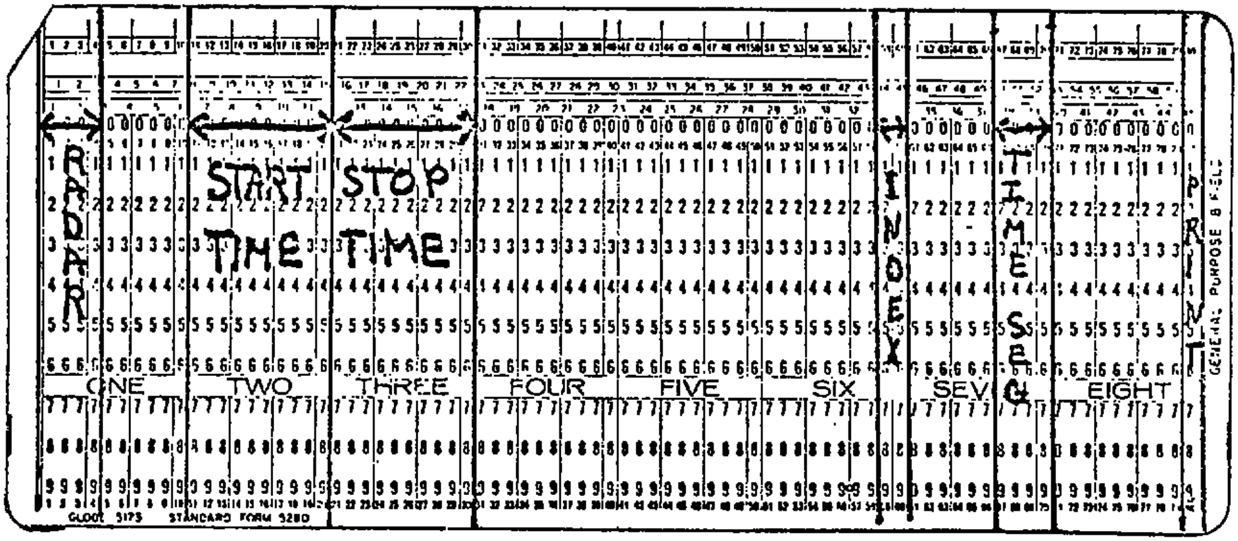
INPUT TAPE ASIGN CARD

FIGURE (3)



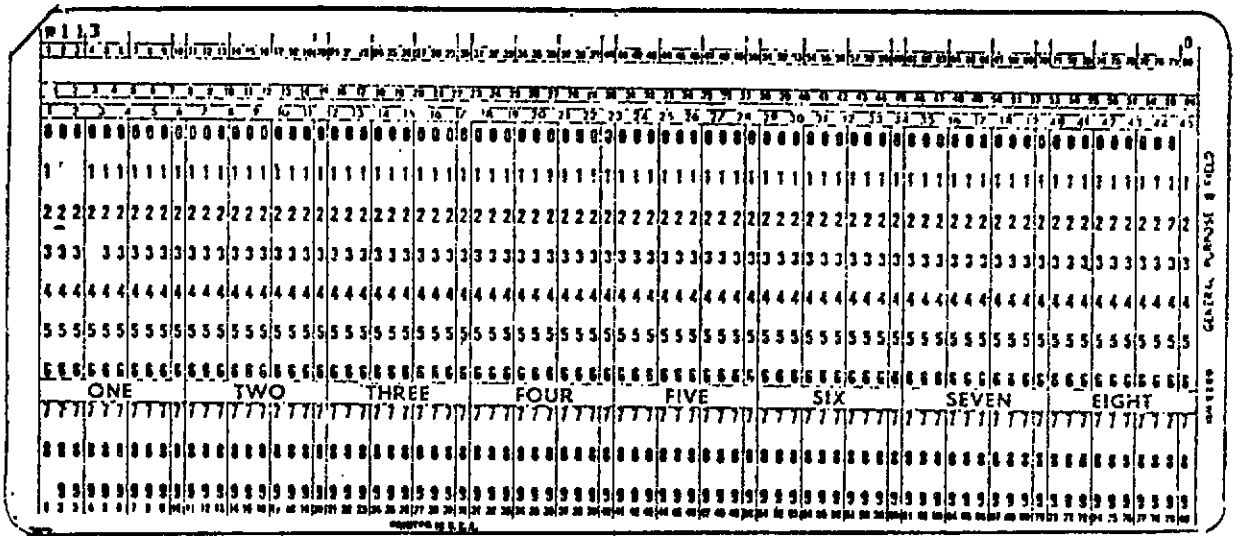
THE DATA CARD

FIGURE (4)



DATA CARD (PROCESS ALL DATA - LONG PRINT)

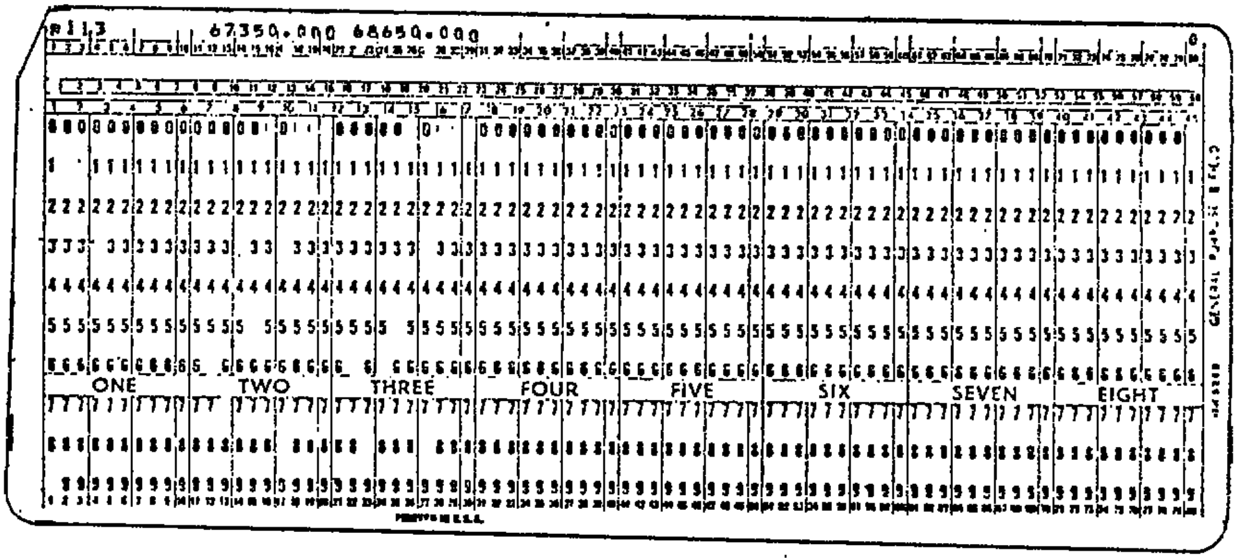
FIGURE (5A)



P113

DATA CARD (START & STOP TIMES - LONG PRINT)

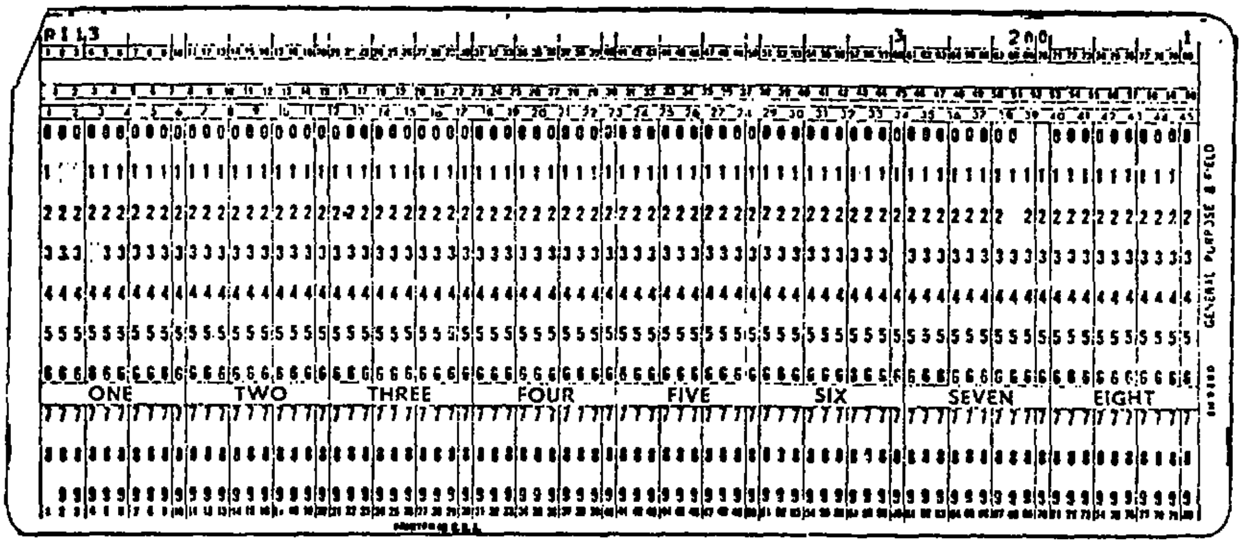
FIGURE (5B)



P113 67350.000 68650.000

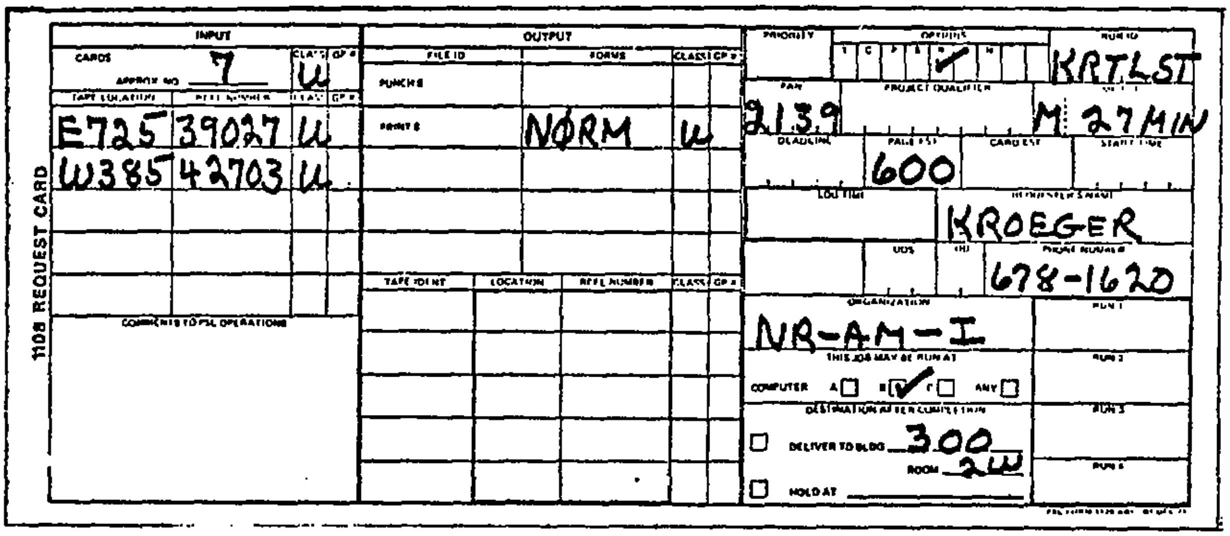
DATA CARD (PROCESS THE THIRD 200 SECOND INTERVAL ON THE TAPE - SHORT PRINT)

FIGURE (5C)



THE RUN REQUEST CARD

FIGURE (6)


1108 REQUEST CARD

INPUT			
CARDS APPROX NO 7		CLASS W	GP #
TAPE LOCATION	REEL NUMBER	CLASS	GP #
E725	39027	W	
W385	42703	W	

COMMENTS TO PSL OPERATIONS

OUTPUT	FILE ID	FORMS	CLASS	GP #
PUNCHES				
PRINTS		NØRM	W	

TAPE IDENT	LOCATION	REEL NUMBER	CLASS	GP #

PRIORITY

OPTIONS: T C P S D ✓ N

RUN ID: KRTLST

PAN: 2139

PROJECT QUALIFIER

M 27MIN

DEADLINE

PAGE EST: 600

CARD EST

START TIME

LOG TIME

REQUESTER'S NAME: KROEGER

PHONE NUMBER: 678-1620

ORGANIZATION: NR-AM-I

THIS JOB MAY BE RUN AT

COMPUTER A ☐ B ☑ C ☐ ANY ☐

DESTINATION AFTER COMPLETION

☐ DELIVER TO BLDG 300

ROOM 2W

☐ HOLD AT

RUN 1

RUN 2

RUN 3

RUN 4

```
SA,.ROYRA
-01/23/74-11:58:54 (,0)


UNPACK     ENTRY POINT 000415


D: CODE(1) 000427; DATA(0) 006324; BLANK COMMON(2) 000000

CKS:

     000323
F    000004
ATE  000132
     000002


FERENCES (BLOCK, NAME)

AN
US
2S
R3S


IGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

010 10L          0001     000363 I10L       0001     000276 I18L        0001     000374 I20L
327 128L         0001     000015 I5L        0001     000107 I55L        0001     000016 20L
046 30L          0001     000053 35L        0000     006266 84F         0004 I 000000 ENDFI
037 IA           0004 I 000002 ICONTR       0003 I 000171 ID            0000 I 006263 IDT
264 II           0000 I 006265 IIBK         0004 I 000003 ILIFT         0000     006277 INJPS
001 IR           0003 I 000133 IRD          0000 I 006262 IRSTAT        0003 I 000265 ISTAT
074 IVALIB       0005 I 000000 IVALID       0005 I 000036 IVALIS        0000 I 006257 IWC
255 L            0000 I 006254 LCODE        0000 I 006256 M             0000 I 006253 MASK
260 NORAD        0004 I 000001 PARITY       0006 R 000001 SKIP          0003 R 000000 T


          SUBROUTINE UNPACK                             @ SHORT FORM
          COMMON/INT/T,IR(30),IA(30),IE(30),IRD(30),ID(30),ITQ(30),ISTAT(30)
          COMMON/EOFF/ENDFIL,PARITY,ICONTR,ILIFT
          COMMON/FBRATE/IVALID(30),IVALIS(30),IVALIB(30)
          COMMON/NKK/KK,SKIP
          DIMENSION TAPREC(3241)
          INTEGER ENDFIL,PARITY
          DATA N/0/PARITY/0/
          DATA IONES/0777777600000/                       @16 DATA BITS, ONE SIGN
          DATA MASK/0777740000000/                      @R113 OCT 73
          IF (ENDFIL.NE.0) GO TO 10
          IF (PARITY.NE.0) GO TO 15
          IF (N.GT.0) GO TO 35
       10 ENDFIL = 0
          CALL NTRAN (2,10)                             @POSITION TAPE TO LOAD POINT
       15 PARITY = 0
       20 N = 0
```

```
      CALL NTRAN(2,2,3241,TAPREC,LCODE)      @READ 1 PHYSICAL RECORD
      CALL NTRAN(2,22)
      IF (LCODE.GT.0)  GO TO 30              @RECORD OK
      IF (LCODE.EQ.-3) GO TO 110             @TEST FOR BAD RECORD
      IF (LCODE.EQ.-2) GO TO 120             @TEST FOR EOF
   30 ICONTR = BOOL(TAPREC(1))               @CONTROL WD 0=RAD,1=MET,2=RAD+MET
      L=2
      M = 0
   35 N = N + 1
      IF (N.GT.20) GO TO 20
      IWC=FLD(18,18,TAPREC(L))
      ILIFT= FLD(0,6,TAPREC(L))
      NORAD = (IWC-1)/5                      @NO. OF RADARS PER LOGICAL REC
      T=TAPREC(L+1)/1000.
      DO 60 I=1,NORAD
      IRSTAT = BOOL(TAPREC(M+4))
      IDT = FLD(20,7,IRSTAT)
      II = IDT+1
      IF(II.GT.30) II = 30
      IF(IDT.EQ.44) II=14                            @ RADAR 394
      IF(IDT.EQ.40) II=25                                       @ R350
      IF(IDT.EQ.41) II=26                                       @ R351
      IF(IDT.EQ.42)II=15                  @ RADAR 352
       IF(IDT.EQ.47)II=16                       @RADAR 393A
C
C        ISTAT IS A NEW STATUS WORD.   EXAMPLE  02500701030, 0250 =
C   ALT.SYNC, 07 = CONF. COUNTER, 01 = RUN NO., 03 = TGT NO.,
C   30 = SUBCHANNEL NO.
C
      FLD(4,8,ISTAT(II)) = FLD(12,8,IRSTAT)
      FLD(12,6,ISTAT(II)) = FLD(6,6,IRSTAT)
      FLD(21,3,ISTAT(II)) = FLD(0,3,IRSTAT)
      FLD(27,3,ISTAT(II)) = FLD(3,3,IRSTAT)
      FLD(30,6,ISTAT(II)) = FLD(6,6,IRSTAT)
      ID(II) = IDT                           @ RADAR ID
      IR(II) = FLD(12,24,TAPREC(M+5))        @ RANGE
      IA(II) = FLD(12,17,TAPREC(M+6))        @ AZIMUTH
      IE(II) = FLD(12,17,TAPREC(M+7))        @ ELEVATION
      IRD(II) = FLD(13,23,TAPREC(M+8))       @ RANGE RATE
      ITQ(II)= FLD(33,3,IRSTAT)+16          @NOV73 FOR MPS36
      IVALID(II) = 0                       @ NOV73 FOR MPS36
      IVALID(II)=FLD(32,1,IRSTAT)
      IVALIS(II)=FLD(31,1,IRSTAT)          @  DOPPLER SKIN FLAG
      IVALIB(II)=FLD(30,1,IRSTAT)          @  DOPPLER BEACON FLAG
      IF(II.GT.8) GO TO 118                 @ MPS 36  NOV 73
      GO TO 121
  118 CONTINUE
      IF(FLD(12,1,TAPREC(M+8)).EQ.1) IRD(II)= IRD(II)*(-1)
 84   FORMAT(2(1X,012))
 119  CONTINUE
      GO TO 128

C                            FPS 16 NEG RDOT NOV 73
 121  CONTINUE
      IF(FLD(12,1,TAPREC(M+8)))127,128,127
 127  IRD(II)= IRD(II)-1
      IRD(II)= OR(MASK,IRD(II))
```

```
C                                 FPS 16 NEG ROOT NOV 73

 128     CONTINUE

C             TIME SKIP
        IF(T.LT.SKIP) GO TO 3

        IIBK= FLD(0,36,IRSTAT)                      @ HOUSEKEEPING
        IF(II.EQ.KK)  WRITE(6,84) IIBK, IIBK          @ HOUSEKEEPING
   3    CONTINUE
        M = M+5
   60 CONTINUE
        M = M+2
   80 L = L+IWC+1
        RETURN
  110 PARITY = LCODE                          @ SET FLAG FOR PARITY ERROR
        CALL NTRAN(2,22)
        RETURN
  120 ENDFIL = 1                              @ SET END OF FILE FLAG
        RETURN
        END

COMPILATION:         NO  DIAGNOSTICS.
```

```
040 IRAD        0004 I 000133 IRD        0000 I 001132 IRSIG      0000 I 001163 IRUA
 154 IRUN       0000 I 001135 ISPTS      0004   000265 ISTAT      0003 I 000012 ITD
 202 ITEST      0003 I 003214 ITIME      0004 I 000227 ITQ        0003 I 000011 ITR
217 IUM10       0003 I 003215 IUM6       0003 I 003216 IUM9       0006 I 000074 IVAL
036 IVALIS      0000 I 001130 IVNEG      0000 I 001127 IVPOS      0000 I 001156 J
 157 K          0000 I 001160 L          0000 I 001163 NPOINT     0005 I 000001 PARIT
 152 RTDG       0000 R 001151 SCALE      0000 R 001212 SDREL      0003   000032 SDVL
027 SIGR21      0000 R 001167 SIGX       0000 R 000223 SPR1       0000 R 001213 SRREL
 176 T          0000 R 001175 TEST       0000 R 001207 TF         0000 R 001162 T1
044 TLIFT       0003 R 000035 TSTART     0003 R 000036 TSTOP      0003 R 000021 VEL
 206 VLPR       0000 R 001216 VPP        0000 R 001215 XPER       0000 R 001165 XRAW
000 Z
```

```
      COMMON/MAIN/ IERR,IE(6),   TIN,DT,ITR,ITD(3),ITD3,R,A,E,VEL,
     1DR51,DR21,VEL21,DDR51,DVEL21,SIGR21,SGDR21,SVEL21,SDVL21,
     2DEL51,DEL21,TSTART,TSTOP,INAM,IRAD,IMODE(3),TLIFT,DELT,
     3BUFF(20,81),INAME(9),ICHAN(9),ITIME,IUM6,IUM9,IUM10,IOPT
      COMMON/INT/Z,IR(30),IA(30),IL(30),IRD(30),ID(30),ITQ(30),ISTAT(30)
      COMMON/EOFF/ENDFIL,PARITY,ICONTR,ILIFT
      COMMON/FBRATE/IVALID(30),IVALIS(30),IVALIB(30)
      DIMENSION FINVAR(81)
      DIMENSION  HOLD(2,4,8), IPT(2)
      DIMENSION  SPRI(18,25)
      INTEGER ENDFIL,PARITY
      DATA IMODE/1HB,1HS,1HN/
      DATA INAME/4HR113,4HR123,4HR127,4HR354,4HR352,4HR393,4HR350,4HR351
     1,4H    /
      DATA ICHAN/2,5,8,14,15,16,25,26,30/
      IPOSPT=0              @ COUNTER OF POS VEL POINTS(GT 100 FPS)
      INEGPT=0              @ COUNTER OF NEG VEL POINTS(LT 100 FPS)
      IVPOS =0              @ VALID POS DOPP
      IVNEG =0              @ VALID NEG DOPP
      IDSIG=0
      IRSIG=0
      INNN =0         @ RADAR INTRACK (MUST BE GT 50 FOR PROGRAM TO RUN)
      INPTS=0         @ NUMBER OF POINTS PROCESSED
      ISPTS=0         @ COUNTER FOR DOPPLER SKIN RETURN POINTS
      IBPTS=0         @ COUNTER FOR DOPPLER COHO BEACON RETURN POINTS
      IDBFI=0                            @ DATA IS BAD BUT FLG SAYS GOOD
      IDGFO=0                            @ DATA IS GOOD BUT FLG SAYS BAD
      IKP=0
      IPTCE=0
      IPTC=0
      IPTCB=0
      IOOP1=0
      IOOP2=0
      IPT(1)=21
      IPT(2)=51
      READ(5,2002) INAM,IUM6,TSTART,TSTOP,DELT,TLIFT,IUM10,ITIME,IUM9,
     1IOPT
      WRITE (6,213)
      WRITE (6,214)
      WRITE (6,212)
      WRITE (6,215) INAM
```

```
      WRITE (6,216) TSTART
      WRITE (6,217) TSTOP
      WRITE (6,218) DELT
      WRITE (6,212)
      WRITE(6,220)
      WRITE(6,221) IUM10,ITIME
      WRITE(6,212)
      IF(IOPT.EQ.0) WRITE (6,223)
      IF(IOPT.EQ.1) WRITE (6,222)
      IF(IOPT.LT.0.OR.IOPT.GT.1) WRITE(6,224)
 3000 FORMAT(55H  THE FOLLOWING LIST GIVES ERROR CODE DEFINITIONS.      )
 3001 FORMAT(55H E100000)    =DOPPLER DVES VALID FLAG HAS CHANGED.      )
 3002 FORMAT(55H E 20000)    =DOPPLER 21PT RAW DATA SIGMA HAS CHANGED.  )
 3003 FORMAT(55H E  3000)    =VELOCITY ERROR G.T. 14.31 F.P.S.          )
 3004 FORMAT(55H E   400)    =TIME HAS A GAP(NOT .05 SEC)DERIVATIVES BAD)
 3005 FORMAT(55H E    50)    =RADAR HAS CHANGED ITS TRACK MODE.         )
 3006 FORMAT(55H E     6)    =NOT PRESENTLY ASSIGNED.                   )
 3007 FORMAT(55H                                                        )
 3008 FORMAT(55H E 20050)    =ERRORS 2 AND 5 BOTH PRESENT(EXAMPLE)      )
      WRITE(6,212)
      WRITE(6,3000)
      WRITE(6,3007)
      WRITE(6,3001)
      WRITE(6,3002)
      WRITE(6,3003)
      WRITE(6,3004)
      WRITE(6,3005)
      WRITE(6,3006)
      WRITE(6,3007)
      WRITE(6,3008)
      WRITE(6,3007)
      WRITE(6,213)
      WRITE (6,225)
      WRITE (6,226)
      WRITE (6,227)
      WRITE (6,3050)
      WRITE (6,225)
C
C  FROM DATA CARDS COMPUTE RADAR ID FOR UNPACK AND SET FLAGS,CONSTANTS
C
      DO 1 I=1,9
      IIRR=ICHAN(I)
      IF(INAME(I).EQ.INAM)GO TO 3
    1 CONTINUE
   2  FORMAT(99H THE RADAR SPECIFIED ON THE DATA CARD IS NOT CATALOGED A
     1S A RANGE RATE RADAR IN THIS PROGRAM. STOP.)
      WRITE(6,212)
      WRITE(6,212)
      WRITE(6,2)
      WRITE(6,212)
      WRITE(6,212)
      STOP
    3 CONTINUE
      SCALE = 3.14159265358979300/(2.**8.**5)        @ ANGLE IN RADIANS
      RTDG  =          57.2957795131                 @ ANGLE IN DEGREES
      IRUA=TSTART*1000.+TSTOP*1000.
      IRUN=IRUA + IUM10+ITIME
```

```
      IRUB=IUMIO+ ITIME
C
C SHIFT DATA HOLDING ARRAYS
C
 100  DO 20I=1,8
      DO 10J=1,80
      K= J+1
  10  BUFF(I,J)=BUFF(I,K)
  20  CONTINUE
      DO 40I=1,9
      K=I+8
      DO 30J=1,40
      L=J+1
  30  BUFF(K,J)=BUFF(K,L)
  40  CONTINUE
C
C LOAD INPUT VALUES FROM REALTIME LOG TAPE
C
      CALL  UNPACK              @ BUFF(I,81) = NEWEST POINT
C
      BUFF(5,81)= -100.0              @ TRACK MODE  NEGATIVE= NO TRACK
      ITQ(IIRR)=ITQ(IIRR)-16
      IF(ITQ(IIRR).EQ.4)BUFF(5,81)=4.0      @ TRACK MODE IS BEACON
      IF(ITQ(IIRR).EQ.3)BUFF(5,81)=3.0      @ TRACK MODE IS SKIN
      BUFF(1,81)=IR(IIRR)                   @ RANGE YDS
      BUFF(1,81)=BUFF(1,81)*3.0             @ RANGE FT
      BUFF(2,81)=IRD(IIRR)                  @ RANGE RATE
      BUFF(2,81)=BUFF(2,81)*.0075           @ RANGE RATE IN F.P.S.
      BUFF(3,81)=IA(IIRR)                   @ AZIMUTH
      BUFF(3,81)=BUFF(3,81)* SCALE          @ AZIMUTH IN RADIANS
      BUFF(4,81)=IL(IIRR)                   @ ELEVATION
      BUFF(4,81)=BUFF(4,81)* SCALE          @ ELEVATION IN RADIANS
      Z=Z-.090
      BUFF(15,41)=Z-2.0
      BUFF(6,81)=IVALID(IIRR)
      BUFF(7,81)=BOOL(IVALIS(IIRR))
       BUFF(8,81)=BOOL(IVALIB(IIRR))
C
C
      IF(IRUN.EQ.0) GO TO 440         @ IF TRANSFER, PROCESS WHOLE TAPE
      IF(IRUB.EQ.0) GO TO 441         @ IF TRANSFER,USE TSTART & TSTOP
      IF(IUMIO.LT.2) GO TO 440        @ IF TRANSFER,PROCESS 1ST ITIME PTS
      ITST =(IUMIO-1)*(ITIME*20)
      IOOPI=IOOPI+1                   @  SPACE TAPE OVER 1ST N ITIMES
      IF(IOOPI.LT.ITST) GO TO 100
      IRUN=0
      GO TO 440
 441  IF (BUFF(15,41).LT.TSTART) GO TO 100
      IRUN=0
 440  CONTINUE
C
C THE FOLLOWING TEST DOES NOT PERMIT RUN TO BEGIN UNTIL DATA ARRAYS
C      HAVE ENOUGH IN-TRACK  RADAR DATA  TO INITIALIZE FILTERS
C      (51 CONSECUTIVE POINTS IN BEACON OR SKIN TRACK)
C
C
      IF(INNN.GT.50)GO TO 1002
```

```
      INNN =0
      DO 1001 I=1,51
      J= I+15
      IF(BUFF(5,J).GT.0.0) INNN=INNN+1
 1001 CONTINUE
      TI= BUFF(15,41)     @ START TIME OF FUN
      GO TO 100
 1002 CONTINUE
C
C     SMOOTH  RANGE AND RANGE RATE  USING 21 AND 51 POINT  SMOOTHING
C
      DO 41 I=1,2                     @ FIT  21PT  THEN 51PT
      NPOINT = IPT(I)
      DERKEY =1.0
      DO 42 J=1,2                      @ FIT  RANGE  THEB RANGERATE
      DO 43 K=1,81                    @ LOAD RAW DATA (81 PT ARRAY)
  43  FINVAR(K)=BUFF(J,K)
C
C     CALL LLL      LLS IS AN UNCONSTRAINED LEAST SQUARES, 2ND ORDER
C                   MOVING ARC FILTER. IT IS COMPLETELY COMPATABLE
C                   THE THE STANDARD  WSMR DATA REDUCTION VAA PROGRAM.
C
      CALL LLL(NPOINT,DERKEY,FINVAR,XRAW,XSM,SIGX,DXSM,DSIGX,DDXSM,
     1DDSIGX,CVAR)
      HOLD(I,J,1)=XRAW              @ RAW MID POINT VALUE
      HOLD(I,J,2)=XSM               @ SMOOTH MID POINT VALUE
      HOLD(I,J,3)=DXSM              @ SMOOTH MID POINT 1ST DERIVATIVE
      HOLD(I,J,4)=DDXSM             @ SMOOTH MID POINT 2ND DERIVATIVE
      HOLD(I,J,5)=SQRT(SIGX)        @ SMOOTH MID POINT 1 SIGMA ERR. EST.
      HOLD(I,J,6)=SQRT(DSIGX)       @ 1ST DERIVATIVE   1 SIGMA ERR. EST.
      HOLD(I,J,7)=SQRT(DDSIGX)      @ 2ND DERIVATIVE   1 SIGMA ERR. EST.
      HOLD(I,J,8)=CVAR              @ VARIANCE  OF THE TOTAL CURVE DATA
  42  CONTINUE
  41  CONTINUE
C
C LOAD INTO  DATA BUFFER ALL  SMOOTH DATA, FLAGS, AND VARIANCES
C THAT ARE TO BE SAVED FOR A TWO SECOND INTERVAL ...USED FOR PRINT/EDIT
C
C
      BUFF(9,41)= HOLD(2,1,4)          @  RANGE 2ND DERIVATIVE   51PT
      BUFF(10,41)=HOLD(1,2,3)          @  RANGE RATE DERIVATIVE  21PT
      BUFF(11,41)=HOLD(1,1,6)          @  RANGE 1ST DERIV. SIGMA 21PT
      BUFF(12,41)=HOLD(1,2,5)/.3279    @  RANGE RATE SIGMA       21PT
      BUFF(13,41)=HOLD(2,1,3)          @  RANGE 1ST DERIV.       51PT
      BUFF(14,41)= HOLD(1,2,2)         @  RANGE RATE  (SMOOTH) 21PT
C
C     TEST      ERROR PRINT OUTS  AND SET  FLAGS
C
      IE(1)=0
ITIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF(BUFF(6,40).NE.BUFF(6,41))IE(1)=100000 @ HAS DOP FLAG CHANGED
      IE(2)=0
      IF(BUFF(12,41).GT.1.2) IE(2) =20000 @VEL SIGMA GT 1.2 FPS
      IE(3)=0
      TEST=ABS(HOLD(2,1,3)-HOLD(1,2,1))
      IF(TEST.GT.14.31) IE(3)=3000         @VEL ERROR GT 14.31 FPS
      IE(4)=0
```

```
          TEST= ABS(BUFF(15,41)-BUFF(15,40))
          IF(TEST.GT..06.OR.TEST.LT..045) IE(4)=400 @  TIME GAP ERROR TEST
          IE(5)=0
 STIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
          IF(BUFF(5,40).NE.BUFF(5,41)) IE(5)=50      @ RADAR CHANGED TRK MD
          IE(6)=0                                     @  NOT USED
      C
      C
      C FLAGS FOR ERRORS PRINTED ON THE OUTPUT LISTING IN THE FIRST
      C        COLUMN  AND WILL APPEAR  AS FOLLOWS (OR IN COMBINATIONS):
      C
          IERR=0
          IERR= IE(1)+IE(2)+IE(3)+IE(4)+IE(5)+IE(6)
          BUFF(17,41) = IERR
      C
      C  E100000 )      = DOPPLER  TRACK FLAG HAS CHANGED
      C  E020000 )      = DOPPLER  1 SIGMA  G.T. 1.2 FPS
      C  E003000 )      = VELOCITY ERROR  G.T. 14.31 FPS
      C  E000400 )      = TIME HAS A GAP - DERIVATIVES BAD
      C  E000050 )      = RADAR HAS CHANGED  TRACK
      C  E000006 )      = ( FLAG  NOT USED )
      C
      C  E020050 )      =  ERRORS 2 AND 5  ARE BOTH PRESENT
  X   C
          T=BUFF(15,41)-TLIFT
           DT=BUFF(15,40)-BUFF(15,41)
           IF(BUFF(5,41).GT.1.) ITR= IMODE(2)        @ SKIN TRK
           IF(BUFF(5,41).GT.3.) ITR= IMODE(1)        @ BEACON TRK
           IF(BUFF(5,41).LT.0.) ITR= IMODE(3)        @ NO TRK
           ITD(1)=BUFF(6,41)                         @ VEL MODE
          ITD(2)=BOOL(BUFF(7,41))
          ITD(3)=BOOL(BUFF(8,41))
           R=BUFF(1,41)                              @ RANGE FT.
           A=BUFF(3,41)* RTDG                        @ AZ     DEG
           E=BUFF(4,41)* RTDG                        @ EL     DEG
           DDR51 = BUFF(9,41)                        @ RANGE ACC
           DEL21 = BUFF(10,41)                       @ VEL    ACC
           SGDR21= BUFF(11,41)                       @ RVEL 1SIG
           SVEL21=BUFF(12,41)                        @ DOP  1SIG
           DR21  =BUFF(13,41)                        @ RANGE VEL
          VEL=HOLD(1,2,1)
           DEV21 =HOLD(1,1,3) - HOLD(1,2,1)          @ RDOT- RAW VEL
           DEV51 =HOLD(2,1,3) - HOLD(1,2,1)          @ RDOT- RAW VEL
          INPTS=INPTS+1
          IF(BUFF(5,41).LT.0.) GO TO 3010   @ ONLY COUNTERRORS RADAR INTRACK
      C
      C  TEST COUNT FOR GOOD DOPP EITHER APPROACHING OR LEAVING RADAR
      C  COUNT MADE ONLY FOR VEL G.T. ABS(100 FPS)
      C
          IF(ABS(HOLD(2,1,3)).LT.100.0) GO TO  556  @ IF TRANSFER CIRCLING
          IF(HOLD(2,1,3).LT.-100.0) GO TO 557
          IPOSPT=IPOSPT+1                            @ TARGET RECEEDING
          IF(ABS(DEV51).LT.14.31)IVPOS=IVPOS+1       @ TARGET RECEEDING
          GO TO 56                                   @ TARGET RECEEDING
   557    CONTINUE                                   @ TARGET APPROACHING
          INEGPT=INEGPT+1                            @ TARGET APPROACHING
          IF(ABS(DEV51).LT.14.31)IVNEG=IVNEG+1       @ TARGET APPROACHING
```

```
 556   CONTINUE
C
C
       IF(ITD(2).EQ.1) ISPTS=ISPTS+1         @ COUNT DOP SKIN PTS
       IF(ITD(3).EQ.1) IBPTS=IBPTS+1         @ COUNT DOP COHO PTS
       IF(BUFF(11,41).LT.6.00) IRSIG =IRSIG+1
       IF(BUFF(12,41).LT.1.2D) IDSIG =IDSIG+1
C
C TEST ERROR WHEN DATA IS BAD BUT DVES VALID SAYS ITS GOOD
C
       IF(ABS(DEVS1).GE.14.3).AND.ITD(1).EQ.1) IDBF1=IDBF1+1
C
C TEST ERROR WHEN DATA IS GOOD BUT DVES VALID SAYS ITS BAD
C
       IF(ABS(DEVS1).LT.14.3).AND.ITD(1).EQ.0) IDGF0=IDGF0+1
 3010  CONTINUE
C
       IF(IOPT.NE.1) GO TO 399       @  SKIP PRINT ERROR ONLY LOGIC
       DO 350 JJ=1,24
       J=1+JJ
       DO 351 I=1,18
  351  SPRI(I,JJ)=SPRI(I,J)
  350  CONTINUE
       SPRI(1,25)=BOOL (IERR)
       SPRI(2,25)=T
       SPRI(3,25)=DT
       SPRI(4,25)=BOOL(ITR)
       SPRI(5,25)=BOOL(ITD(1))
       SPRI(6,25)=BOOL(ITD(2))
       SPRI(7,25)=BOOL(ITD(3))
       SPRI(8,25)=R
       SPRI(9,25)=A
       SPRI(10,25)=E
       SPRI(11,25)=DDR51
       SPRI(12,25)=DEL21
       SPRI(13,25)=SGDR21
       SPRI(14,25)=SVEL21
       SPRI(15,25)=DR21
       SPRI(16,25)=VEL
       SPRI(17,25)=DEV21
       SPRI(18,25)=DEV51
       IKP=IKP+1
       ITEST=0
       DO 352 I=1,25
 352   ITEST=ITEST +(BOOL(SPRI(I,I)))
       IF(ITEST.EQ.0) GO TO  398                       @  NO ERRORS
       IKP= 0
       ITEST=ITEST-(BOOL(SPRI(1,25)))
       IF(ITEST.NE.0) GO TO  399        @IF TRANSFER,PREV. 25 ALREADYDUMPED
       DO 353 I=1,25
       IERR= BOOL  (SPRI(1,I))         @
       T    =       (SPRI(2,I))        @ DUMP
       DT   =       (SPRI(3,I))        @
       ITR =  BOOL(SPRI(4,I))          @ PREVIOUS
       ITD(1)=BOOL(SPRI(5,I))          @
       ITD(2)=BOOL(SPRI(6,I))          @  25
       ITD(3)=BOOL(SPRI(7,I))          @
```

```
      R      = SPRI(8,I)                    @  DATA
      A      = SPRI(9,I)                    @
      E      = SPRI(10,I)                   @  POINTS
      DDR5I  = SPRI(11,I)
      DEL2I  = SPRI(12,I)
      SGDR2I= SPRI(13,I)
      SVEL2I= SPRI(14,I)
      DR2I   = SPRI(15,I)
      VEL    = SPRI(16,I)
      DEV2I  = SPRI(17,I)
      DEV5I  = SPRI(18,I)
      IF(IERR.EQ.0)  GO TO 355
      WRITE(6,2000) IERR,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR5I,DEL2I
     1,SGDR2I,SVEL2I,DR2I,VEL,DEV5I,DEV2I
      GO TO 356
  355 CONTINUE
      WRITE(6,2001) INAM,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR5I,DEL2I
     1,SGDR2I,SVEL2I,DR2I,VEL,DEV5I,DEV2I
  356 CONTINUE
  353 CONTINUE
      GO TO 398
  399 CONTINUE
      IF(IERR.EQ.0)   GO TO 460
      WRITE(6,2000) IERR,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR5I,DEL2I
     1,SGDR2I,SVEL2I,DR2I,VEL,DEV5I,DEV2I
      GO TO  461
  460 CONTINUE
      WRITE(6,2001) INAM,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR5I,DEL2I
     1,SGDR2I,SVEL2I,DR2I,VEL,DEV5I,DEV2I
  461 CONTINUE
  398  CONTINUE
      IF(IOPT.NE.1) GO TO 501
      IF(IKP.LT.100) GO TO 500
      WRITE(6,2001)
      WRITE(6,2001) INAM,T,DT,ITR,ITD(1),ITD(2),ITD(3),R,A,E,DDR5I,DEL2I
     1,SGDR2I,SVEL2I,DR2I,VEL,DEV5I,DEV2I
      WRITE(6,2001)
  501 IKP=0
  500 CONTINUE
C
      IF(BUFF(5,4I).LT.0.)GO TO 300
      IPTC=IPTC+1                             @ TOT NO PTS COUNTER
      IF(IERR.NE.0) IPTCE = IPTCE +1          @ TOT ERRORS COUNTER
      IF(IE(3).NE.0)IPTCB= IPTCB +1           @ BIAS ERROR COUNTER
  300 CONTINUE
      IF(ENDFIL.EQ.1) GO TO  462
C
      IF(ITIME.EQ.0.AND.TSTOP.LT.1.0) GO TO 100  @IF TRANSFR CONT.PROC.
      IF(ITIME.EQ.0) GO TO 443
      ITST=ITIME*20                          @  PROCESS ALL REQ. ITIME POINTS
      IOOP2=IOOP2+1
      IF(IOOP2.LT.ITST) GO TO 100
      GO TO  449
  443 IF(BUFF(15,4I).LT. TSTOP) GO TO 100    @ PROCESS TO TSTOP
      GO TO 449
C
  462 CONTINUE
```

```
449  FNUM = IPTCF*100                         @ CALCULATE
     FDEN = IPTC                              @ PERCENTAGES OF
     ERPR = FNUM/FDEN                         @ TOTAL ERRORS AND
     FNUM = IPTCB*100                         @ BIAS ERRORS
     VLPR = FNUM/FDEN                         @ AND  PRINT
     WRITE(6,213)
     WRITE(6,215) INAM
     WRITE(6,212)
     IF(INNN.LT.51)WRITE (6,4500)
4500 FORMAT(55H RADAR NEVER SHOWED BEACON OR SKIN TRACK - NO DATA      )
     TF= BUFF(15,41)
     WRITE(6,4501) TI,TF
4501 FORMAT(14H START OF RUN=,F10.3,14H  ,END OF RUN=,F10.3)
     WRITE(6,212)
     WRITE(6,4502)IPTC
4502 FORMAT(37H NO. OF POINTS OF INTRACK RADAR DATA=,I10)
4503 FORMAT(37H TOTAL NUMBER OF RAD. PTS. PROCESSED=,I10)
     WRITE(6,3007)
     WRITE(6,4503)INPTS
     WRITE(6,212)
     WRITE(6,450) ERPR,VLPR
     WRITE(6,212)
450  FORMAT(22H PERCENTAGE OF ERRORS=,F5.1,34H        PERCENTAGE OF BIA
    1SED DATA=,F5.1)
     WRITE(6,3007)
     FNUM= IDBFI*100
     EDBFI=FNUM/FDEN
     FNUM= IDGFO*100
     EDGFO=FNUM/FDEN
3011 FORMAT(42H PERCENTAGE OF INVALID DVES W/GOOD DATA = ,F5.1)
3012 FORMAT(42H PERCENTAGE OF VALID   DVES W/BAD  DATA = ,F5.1)
     WRITE(6,3011) EDGFO
     WRITE(6,3007)
     WRITE(6,3012) EDBFI
     WRITE(6,212)
     WRITE(6,3007)
     SDREL =(IDSIG*1000) /IPTC
     SDREL =(SDREL/10.0)+.05
     SRREL =(IRSIG*1000) /IPTC
     SRREL =(SRREL/10.0)+.05
     WRITE(6,4508)SRREL
     WRITE(6,3007)
     WRITE(6,4509)SDREL
4508 FORMAT(42H RELIABILITY OF LOW NOISE ON RANGE SERVO= ,F5.1,8H PERCE
    1NT)
4509 FORMAT(42H RELIABILITY OF LOW NOISE ON DOPP. SERVO= ,F5.1,8H PERCE
    1NT)
     WRITE(6,212)
     GDFLG= 100.0-(EDGFO+EDBFI)
3014 FORMAT(31H RELIABILITY OF VALID TRK FLG= ,F5.1,9H PERCENT.)
     WRITE(6,3014)GDFLG
     WRITE(6,3007)
     XPER=(ISPTS*1000)/IPTC
     XPER=XPER/10.0 +.05
     WRITE(6,4505)XPER
4505 FORMAT(39H RELIABILITY OF DOPP SKIN RETURN FLAG= ,F5.1,8H PERCENT)
     WRITE(6,3007)
```

```
      XPER=(IBPTS*1000)/IPTC
      XPER=XPER/10.0  +.05
      WRITE(6,4506) XPER
 4506 FORMAT(39H RELIABILITY OF DOPP COHO RETURN FLAG= ,F5.1,8H PERCENT)
      WRITE(6,212)
      IF(IPOSPT.EQ.0)  GO TO 558
      VPP=(IVPOS*1000)/IPOSPT
      VPP=(VPP/10.0)+.05
      WRITE(6,570)VPP
      WRITE(6,3007)
 570  FORMAT(53H RELIABILITY OF DOPP VEL WHEN TARGET IS RECEEDING  = ,F5
     1.1,8H PERCENT)
 558  IF(INEGPT.EQ.0)  GO TO 559
      VPP=(IVNEG*1000)/INEGPT
      VPP=(VPP/10.0)+.05
      WRITE(6,571)VPP
 571  FORMAT(53H RELIABILITY OF DOPP VEL WHEN TARGET IS APPROACHING= ,F5
     1.1,8H PERCENT)
 559  CONTINUE
      WRITE(6,212)
      XPER=(IPTC*1000)/INPTS
      XPER=XPER/10.0 +.05
      WRITE(6,4504) XPER
 4504 FORMAT(29H RADAR TRACKING RELIABILITY= ,F5.1,8H PERCENT)
      WRITE(6,3007)
      GDATA= 100.0-VLPR
 3013 FORMAT(31H RELIABILITY OF VELOCITY DATA= ,F5.1,9H PERCENT.)
      WRITE(6,3013)GDATA
      WRITE(6,213)
      WRITE(6,212)
      WRITE(6,212)
 212  FORMAT(//)
 213  FORMAT(1H1)
 214  FORMAT(27H INPUT DATA CARD FOR CHECKS)
 215  FORMAT(24H RADAR TO BE SEARCHED = ,A4)
 216  FORMAT(24H TIME TO START TAPE   = ,F10.3)
 217  FORMAT(24H TIME TO STOP RUN     = ,F10.3)
 218  FORMAT(24H OUTPUT PRINT INTERVAL= ,F10.3)
 219  FORMAT(24H PRINT TIMES BIASED BY= ,F10.3)
 220  FORMAT(66H WHEN THE FOLLOW OPTION IS USED, IT WILL OVERIDE TSTART
     1AND TSTOP.)
 221  FORMAT(16H PRINT ONLY THE ,I2,22H (1ST,2ND,3RD,4TH,ETC),
     113H INTERVAL OF ,I10,18H  SECONDS OF DATA.)
 222  FORMAT(50H ONLY FLAGGED ERRORS WILL BE PRINTED WITH IOPT =1 )
 223  FORMAT(65H ALL DATA WITH AND WITHOUT ERRORS ARE TO BE PRINTED WITH
     1 IOPT = 0)
 224  FORMAT(39H ERROR IN IOPT COL. 80,SHOULD BE 1 OR 0)
 225  FORMAT(130H I*******I**********I*******I*I*I*I*********I*******I*
     1****I*******I********I******I******I*********I**********III*********I
     2*********I)
 3050 FORMAT(130H I*******I**********I*******IR D S BI*********I*******I*
     1****I*******I********I******I******I*********I**********III*********I
     2*********I)
 226  FORMAT(130H IERR FLGI   TIME     I DEL T I TRACK I RANGE   I  AZ  I
     1EL  I DDRNG I DVEL  ISGDR2IISGVL2II RNGDOTSII RAWVEL   III VELERR I
     2 VELERR I)
 227  FORMAT(130H IOR NAM I  (SEC)    I (SEC) I FLAGS I (FT)    I (DEG)I (
```

```
         1DEG)I F/S2  I F/S2  I FPS  I FPS  I  F.P.S. I F.P.S.  III 5IPTS. I
         2 2IPTS. I)
     2000 FORMAT(2H E,I6,2H) ,F10.3,1H ,F7.3,1H ,A1,3(1H ,I1),1H ,F8.0,
         12(1H ,F6.2),2(1H ,F7.0),2(1H ,F6.2),2(1H ,F9.2),2H  ,2(1H ,F8.2))
     2001 FORMAT(5H     ,A4,1H ,F10.3,1H ,F7.3,1H ,A1,3(1H ,I1),1H ,F8.0,
         12(1H ,F6.2),2(1H ,F7.0),2(1H ,F6.2),2(1H ,F9.2),2H  ,2(1H ,F8.2))
     2002 FORMAT(A4,I6,4F10.3,I10,I10,I9,I1)
          STOP
          END

COMPILATION:           2 DIAGNOSTICS.
```

```
LOGR8
-01/23/74-11:59:17 (,0)


LLL        ENTRY POINT 001065


D: CODE(1) 001153; DATA(0) 003324; BLANK COMMON(2) 000000


FERENCES (BLOCK, NAME)

R3S


IGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

040 100L        0001     000032 130G       0001     000056 137G       0001     000106 153G
113 162G        0001     000146 174G       0001     000150 177G       0001     000153 203G
210 220G        0001     000213 224G       0001     000246 236G       0001     000250 241G
320 267G        0001     000330 272G       0001     000276 300L       0001     000363 302G
574 304L        0001     000723 306L       0001     000447 324G       0001     000457 327G
576 361G        0001     000606 364G       0001     000641 374G       0001     000726 416G
761 430G        0001     000025 500L       0001     000142 501L       0001     000202 502L
035 99L         0000 D 000116 A            0000 D 000110 CON          0000 D 001064 D
514 DVV         0000 D 003006 DVVV         0000 D 000000 D21          0000 D 000022 D31
066 D81         0000 I 003220 I            0000 I 003215 IFLAG        0000   003262 INJP
221 J           0000 I 003222 K            0000 I 003217 KSET         0000 R 003223 SUM
207 XINC        0000 R 003204 XPT          0000 D 003211 XTIME        0000 R 003224 ZSTX
```

```
      SUBROUTINE LLL(NPOINT,DERKEY,FINVAR,XRAW,XSM,SIGX,DXSM,DSIGX,
     1 DDXSM,DDSIGX,CVAR)
      DIMENSION D21(3,3),D31(3,3),D51(3,3),D81(3,3)
      DIMENSION CON(3),A(81,3),D(3,81),DV(3,51),DVV(3,31),DVVV(3,21)
      DIMENSION FINVAR(81),XPT(3)
      DOUBLE PRECISION CON,XINC,XTIME,A,D,DV,DVV,DVVV,TIME2
      DOUBLE PRECISION D21,D31,D51,D81
      DATA D21/0.7132455645041464D+01,-0.1885384876010168D-16,
     A -0.6538084341288005D+00,-0.1885384876010168D-16,
     B 0.5194805194805198D+00,0.3101458121036724D-17,
     C -0.6538084341288005D+00,0.3101458121036724D-17,
     D 0.1075514874141876D+00/
      DATA D31/0.1011224592982102D+01,0.3621563955470748D-17,
     A -0.2022449185964203D+00,0.3621563955470748D-17,
     B 0.1612903225806453D+00,-0.1301952241991733D-17,
     C-0.2022449185964203D+00,-0.1301952241991733D-17,
     D 0.7270704823541305D-01/
      DATA D51/0.8363287259751505D-01,0.6722254535623794D-18,
     A -0.4530113932365392D-01,0.6722254535623794D-18,
     B 0.3619909502262448D-01,-0.3641221206796215D-18,
     C -0.4530113932365392D-01,-0.3641221206796215D-18,
     D 0.4414596027090073D-01/
      DATA D81/0.8266057954158927D-02,0.4222436764700501D-18,
     A -0.1129694587068384D-01,0.4222436764700501D-18,
```

```
     B 0.90334236675700260-02,-0.67611934497257420-18,
     C -0.11296945870683840-01,-0.67611934497257410-18,
     D 0.27784838368946900-01/
       DATA IFLAG/1/
C
C
C      SYMBOLIC DICTIONARY
C
C      NPOINT = NO. OF PTS. OVER WHICH CURVE IS TO BE FITTED.
C      DERKEY = 1.0, COMPUTE DERIVATIVES OF SECOND DEG. EQ.
C      DERKEY = 0.0, NO DERIVATIVES COMPUTED.  SIMPLY FIT INPUT DATA.
C      FINVAR = INPUT DATA ARRAY WHICH IS ALWAYS 81-PTS.
C      XRAW = RAW INPUT VALUE AT THE 41-PT.
C      XSM = SMOOTH VALUE AT THE 41-PT.
C      SIGX = VARIANCE OF POSITION AT THE 41-PT.
C      DXSM = SMOOTH FIRST DERIVATIVE AT THE 41-PT.
C      DSIGX = VARIANCE OF FIRST DERIVATIVE AT THE 41-PT.
C      DDXSM = SMOOTH SECOND DERIVATIVE AT THE 41-PT.
C      DDSIGX = VARIANCE OF SECOND DERIVATIVE AT THE 41-PT.
C      CVAR = VARIANCE OF SECOND DEG. CURVE FIT.
C      XINC = TIME INCREMENTING CONSTANT FOR--A--MATRIX.
C      XTIME = TIME GENERATED FOR--A--MATRIX.
C      TIMEZ = TIME SQUARED GENERATED FOR--A--MATRIX.
C      A(I,J) = TRANSFORMATION MATRIX TO TRANSFORM THE CONSTANTS OF
C               A SECOND DEGREE EQ. TO SMOOTH POSITION.
C      CON(3) = A(I,3) = 1.0, OF TRANSFORMATION MATRIX.
C      CON(2) = A(I,2) = TIME OF PT. RELATIVE TO STARTING
C               TIME OF CURVE FIT.
C      CON(1) = A(I,1) = TIME SQUARED OF PT. RELATIVE TO STARTING
C               TIME OF CURVE FIT.
C      IX = NO. OF PTS. SECOND DEGREE EQ. IS TO BE FITTED OVER.
C      KSET = NO. OF PTS. TRAVERSED TO THE RIGHT AND LEFT ABOUT
C             MID-PT. REFERENCE TIME.  REFERENCE TIME STARTS AT ZERO.
C      THIS SYMBOL (-) IS NOT A MINUS SIGN; IT IS A DASH IN THE EQS.
C      D21 = (A-TRANSPOSE*A)-INVERSE MATRIX FOR A 21-PT. CURVE FIT.
C      D31 = (A-TRANSPOSE*A)-INVERSE MATRIX FOR A 31-PT. CURVE FIT.
C      D51 = (A-TRANSPOSE*A)-INVERSE MATRIX FOR A 51-PT. CURVE FIT.
C      D81 = (A-TRANSPOSE*A)-INVERSE MATRIX FOR A 81-PT. CURVE FIT.
C      D = MATRIX TO TRANSFORM 81-PTS. OF DATA INTO THE 3 PARAMETERS
C          OF THE SECOND DEG. EQ.
C      DV = MATRIX TO TRANSFORM 51-PTS. OF DATA INTO THE 3 PARAMETERS
C           OF THE SECOND DEG. EQ.
C      DVV = MATRIX TO TRANSFORM 31-PTS. OF DATA INTO THE 3 PARAMETERS
C            OF THE SECOND DEG. EQ.
C      DVVV = MATRIX TO TRANSFORM 21-PTS. OF DATA INTO THE 3 PARAMETERS
C             OF THE SECOND DEG. EQ.
C
C
C
C      THE SET OF INSTRUCTIONS BETWEEN STATEMENT NUMBERS 500 AND 300
C      ARE EXECUTED ONLY ONCE.  INITIALLY, IFLAG IS SET TO ONE IN
C      ORDER TO EXECUTE SUCH INSTRUCTIONS.
C      IX--IS SET FOR AN 81-PT. CURVE FIT.
C      KSET--IS SET TO THE LOWER AND UPPER BOUND SPAN ABOUT MID-PT.
C      REFERENCE.  REFERENCE TIME STARTS AT ZERO AND INCREMENTS BY
C      0.05 SECONDS.
C      SET CON(3) TO ONE FOR--A--MATRIX.
```

```
C
      IF(IFLAG.EQ.0)GO TO 300
      IX = 81
      KSET = 41
      CON(3) = 1.0
C
C     GENERATE TIME INCREMENT(XINC), TIME(CON(2)), AND TIME SQUARED
C     (CON(1)) FOR--A(I,J)--MATRIX.
C     LOAD COMPUTED VALUES(CON(I)) INTO--A(I,J)--MATRIX.
C
500   DO 5 I=1,IX
      XINC = I-KSET
      XTIME = 5.0D-02*XINC
      CON(1) = XTIME**2
      CON(2) = XTIME
      DO 5 J=1,3
5     A(I,J) = CON(J)
C
C     SELECT THE 51-PT., OR 31-PT., OR 21-PT., PATH DETERMINED BY
C     THE PRESET VALUE OF --IX.
C
      IF(IX.EQ.51) GO TO 501
      IF(IX.EQ.31) GO TO 502
      IF(IX.EQ.21) GO TO 503
C
C     GENERATE THE DATA TRANSFORMATION MATRIX--D--FOR THE 81-PT. FIT.
C
      DO 7 I=1,3
      DO 7 J=1,81
      D(I,J) = 0.0
      DO 7 K=1,3
7     D(I,J) = D(I,J)+D81(I,K)*A(J,K)
      IX = 51
      KSET = 26
      GO TO 500
C
C     GENERATE THE DATA TRANSFORMATION MATRIX--DV--FOR THE 51-PT. FIT.
C
501   DO 8 I=1,3
      DO 8 J=1,51
      DV(I,J) = 0.0
      DO 8 K=1,3
8     DV(I,J) = DV(I,J)+D51(I,K)*A(J,K)
      IX = 31
      KSET = 16
      GO TO 500
C
C     GENERATE THE DATA TRANSFORMATION MATRIX-DVV-FOR 31-PT. CURVE FIT.
C
502   DO 9 I=1,3
      DO 9 J=1,31
      DVV(I,J) = 0.0
      DO 9 K=1,3
9     DVV(I,J) = DVV(I,J)+D31(I,K)*A(J,K)
      IX = 21
      KSET = 11
      GO TO 500
```

```
      C
      C        GENERATE DATA TRANSFORMATION MATRIX-DVVV-FOR 21-PT. CURVE FIT.
      C
      503      DO 10 I=1,3
               DO 10 J=1,21
               DVVV(I,J) = 0.0
               DO 10 K=1,3
      10       DVVV(I,J) = DVVV(I,J)+D21(I,K)*A(J,K)
      C
      C        SET IFLAG TO ZERO TO SKIP STATEMENT NUMBERS 500 THROUGH 300.
      C
               IFLAG=0
      C
      C        SET--SUM--TO ZERO, (SUMMATION OF RESIDUALS SQUARED)
      C        SET PARAMETERS--A,B,C-(XPT(I))--OF SECOND DEG. EQ. TO ZERO.
      C
      300      SUM = 0.0
               XPT(1) = 0.0
               XPT(2) = 0.0
               XPT(3) = 0.0
      C
      C        SELECT THE APPROPRIATE PATH FOR THE NO. OF PTS. USED IN CURVE FIT
      C
               IF(NPOINT.EQ.81)GO TO 306
               IF(NPOINT.EQ.51)GO TO 304
               IF(NPOINT.EQ.31)GO TO 302
      C
      C        COMPUTE PARAMETERS, A,B,C-(XPT(I)) FOR SECOND DEG. EQ.
      C        FOR A 21-PT. CURVE FIT.
      C        LOAD SMOOTH VALUE AT 41-PT. INTO--XSM.
      C        COMPUTE SUMMATION OF RESIDUALS SQUARED--SUM.
      C
               DO 301 I=1,3
               DO 301 J=31,51
               K=J-30
      301      XPT(I) = XPT(I)+DVVV(I,K)*FINVAR(J)
               XSM = XPT(3)
               DO 401 I=1,21
               XINC = I-11
               XTIME = 5.0D-02*XINC
               TIME2 = XTIME**2
               ZSTX = XPT(1)*TIME2+XPT(2)*XTIME+XPT(3)
               K=I+30
      401      SUM = SUM+(FINVAR(K)-ZSTX)**2
      C
      C        LOAD CURVE VARIANCE INTO--CVAR.
      C        CALCULATE MID-PT. VARIANCE OF POSITION--SIGX.
      C
               CVAR = SUM/18.0
               SIGX = 0.597508263E-02*SUM
      C
      C        IF--DERKEY--EQUALS ONE, LOAD IN FIRST DERIVATIVE-(DXSM),
      C        COMPUTE VARIANCES OF FIRST DERIVATIVE-(DSIGX), AND VARIANCE OF
      C        THE SECOND DERIVATIVE-(DDSIGX).
      C
   STIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
               IF(DERKEY.EQ.0.0)GO TO 100
```

```
         DXSM = XPT(2)
         DSIGX = 0.28860C288E-01*SUM
         DDSIGX = 0.158499013E+01*SUM
         GO TO 99
C
C        COMPUTE PARAMETERS, A,B,C-(XPT(I)) FOR SECOND DEG. EQ.
C        FOR A 31-PT. CURVE FIT.
C        LOAD SMOOTH VALUE AT 41-PT. INTO--XSM.
C        COMPUTE SUMMATION OF RESIDUALS SQUARED--SUM.
C
302      DO 303 I=1,3
         DO 303 J=26,56
         K=J-25
303      XPT(I) = XPT(I)+DVV(I,K)*FINVAR(J)
         XSM = XPT(3)
         DO 402 I=1,31
         XINC = I-16
         XTIME = 5.0D-02*XINC
         TIME2 = XTIME**2
         ZSTX = XPT(1)*TIME2+XPT(2)*XTIME+XPT(3)
         K=I+25
402      SUM = SUM+(FINVAR(K)-ZSTX)**2
C
C        LOAD CURVE VARIANCE INTO--CVAR.
C        CALCULATE MID-PT. VARIANCE OF POSITION--SIGX.
C
         CVAR = SUM/28.0
         SIGX = 0.259668025E-02*SUM
C
C        IF--DERKEY--EQUALS ONE, LOAD IN FIRST DERIVATIVE-(DXSM),
C        COMPUTE VARIANCES OF FIRST DERIVATIVE-(DSIGX), AND VARIANCE OF
C        THE SECOND DERIVATIVE-(DDSIGX).
C
STIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
         IF(DERKEY.EQ.0.0)GO TO 100
         DXSM = XPT(2)
         DSIGX = 0.576036860E-02*SUM
         DDSIGX = 0.144460648E+00*SUM
         GO TO 99
C
C        COMPUTE PARAMETERS, A,B,C-(XPT(I)) FOR SECOND DEG. EQ.
C        FOR A 51-PT. CURVE FIT.
C        LOAD SMOOTH VALUE AT 41-PT. INTO--XSM.
C        COMPUTE SUMMATION OF RESIDUALS SQUARED--SUM.
C
304      DO 305 I=1,3
         DO 305 J=16,66
         K=J-15
305      XPT(I) = XPT(I)+DV(I,K)*FINVAR(J)
         XSM = XPT(3)
         DO 403 I=1,51
         XINC = I-26
         XTIME = 5.0D-02*XINC
         TIME2 = XTIME**2
         ZSTX = XPT(1)*TIME2+XPT(2)*XTIME+XPT(3)
         K=I+15
403      SUM = SUM+(FINVAR(K)-ZSTX)**2
```

```
      C
      C       LOAD CURVE VARIANCE INTO--CVAR.
      C       CALCULATE MID-PT. VARIANCE OF POSITION--SIGX.
      C
              CVAR = SUM/48.0
              SIGX = 0.919707498E-03*SUM
      C
      C       IF--DERKEY--EQUALS ONE, LOAD IN FIRST DERIVATIVE-(DXSM),
      C       COMPUTE VARIANCES OF FIRST DERIVATIVE-(DSIGX), AND VARIANCE OF
      C       THE SECOND DERIVATIVE-(DDSIGX).
      C
 STIC*   THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
              IF(DERKEY.EQ.0.0)GO TO 100
              DXSM = XPT(2)
              DSIGX = 0.754147804E-03*SUM
              DDSIGX = 0.696940604E-02*SUM
              GO TO 99
      C
      C       COMPUTE PARAMETERS, A,B,C-(XPT(I)) FOR SECOND DEG. EQ.
      C       FOR A 81-PT. CURVE FIT.
      C       LOAD SMOOTH VALUE AT 41-PT. INTO--XSM.
      C       COMPUTE SUMMATION OF RESIDUALS SQUARED--SUM.
      C
      306     DO 307 I=1,3
              DO 307 J=1,81
      307     XPT(I) = XPT(I)+D(I,J)*FINVAR(J)
              XSM = XPT(3)
              DO 404 I=1,81
              XINC = I-41
              XTIME = 5.0D-02*XINC
              TIME2 = XTIME**2
              ZSTX = XPT(1)*TIME2+XPT(2)*XTIME+XPT(3)
      404     SUM = SUM+(FINVAR(I)-ZSTX)**2
      C
      C       LOAD CURVE VARIANCE INTO--CVAR.
      C       CALCULATE MID-PT. VARIANCE OF POSITION--SIGX.
      C
              CVAR = SUM/78.0
              SIGX = 0.356215871E-03*SUM
      C
      C       IF--DERKEY--EQUALS ONE, LOAD IN FIRST DERIVATIVE-(DXSM),
      C       COMPUTE VARIANCES OF FIRST DERIVATIVE-(DSIGX), AND VARIANCE OF
      C       THE SECOND DERIVATIVE-(DDSIGX).
      C
 STIC*   THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
              IF(DERKEY.EQ.0.0)GO TO 100
              DXSM = XPT(2)
              DSIGX = 0.115813123E-03*SUM
              DDSIGX = 0.423900405E-03*SUM
      C
      C       CALCULATE VARIANCE OF SECOND DERIVATIVE-(DDXSM).
      C       LOAD IN RAW POSITION AT 41-PT. INTO--XRAW.
      C
       99     DDXSM = 2.0*XPT(1)
      100     XRAW = FINVAR(41)
              RETURN
              END
```

APPENDIX C

POTENTIAL BENEFITS
OF
COHERENT C-BAND DOPPLER RANGE-RATE DATA

By

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NASA/Wallops Station
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POTENTIAL BENEFITS OF COHERENT C-BAND DOPPLER RANGE-RATE DATA

C-Band tracking radars equipped with Coherent Signal Processors (CSP) provide precision range-rate data for various applications. The following discussion will attempt to display the utility of range-rate data in terms of Best Estimate of Trajectory (BET) improvement and feature extraction. All of the data shown were collected by the AN/FPQ-6 radar at Wallops Island.

Figure 1 displays a classic problem for launch ranges - trajectory determination during staging. The velocity vs. time trace in figure 1 is from the BET solution of standard skin track range, azimuth, and elevation (RAE) data from a typical NIKE launch at Wallops Island. The computer software that was used to process the trajectory is a state-of-the-art Kalman Filter, similar in design to many range safety real-time filters used nationally. A familiar technique of destroying the memory of the filter at known staging times was utilized in this data analysis to assist in transient response at burn and burn out, but the velocity solution still exhibits classic overshoot and subsequent undershoot. The velocity trace in figure 2 was made with exactly the same computer set-up, except the CSP range-rate data was weighted in the solution.

Figures 3, 4, and 5 are from the tracking data of a super-critical designed fuselage that was dropped from an aircraft. The purpose of the test was to determine the drag coefficient of the body as the velocity passed through mach 1. The test was designed so as to maximize the velocity vector in the direction of the radar range to obtain high quality range-rate information from the CSP. Figure 3 and 4 contrast the solution of acceleration vs. velocity without and with range-rate data. In this case the experiment was looking for a transient in the trajectory, and the CSP was able to contribute greatly to the feature extraction. Figure 5 displays the range-rate residuals to the trajectory displayed in figure 4. The RMS noise (skin track), with four measurements edited, was 8 cm/sec.

As was discussed in figures 1 and 2, the classic problem of any real time or end-point filter such as the Kalman, is overshoot, or equivalently, filter lag. This is particularly evident when solving for high order terms, such as velocity and acceleration, from measurements of position, such as RAE. The filter must process a series of position measurements before the higher order terms are observable, and the result is a time lag. One such observable parameter is aircraft bank angle. The computer software used for most of this paper has an optional dynamic model for aircraft tracking, with bank angle and longitudinal acceleration being the highest order terms in the model. Figure 6 displays the X-Y ground trace of an aircraft flight tracked by the Wallops AN/FPQ-6 radar. The aircraft was equipped with a coherent transponder, and CSP range-rate data was collected along with the normal beacon track RAE (gross spectrum) data. Figures 7 and 8 contrast the BET bank angle without and with range-rate. Notice the time lag of approximately 3 seconds in the solution without range rate. Figure 9 displays the range-rate residuals, here with an RMS of 2.9 cm/sec. Some shadowing of the transponder may have occured in this data, since other segments of the track exhibit 2.0 cm/sec RMS.

The purpose of the above track was to provide an altitude standard with which to compare the measurements from the NRL nanosecond radar altimeter that was on the aircraft. Figure 10 displays the solution for altitude above the spheriod as determined by the altimeter (stars) and as determined by the radar (solid line). The agreement between the two systems is generally 10-20 cm over this one minute span of data, showing the potential for both CSP tracking data and microwave altimetry.

To round out the spectrum of CSP applications, a short span (20 seconds) of skin track range-rate data from a GEOS-II track was integrated to generate precise range data. Figure 11 displays the orbital accuracy by comparing range measurements from a collocated laser ranging system. The X's represent the laser residuals to an orbit determined by 20 seconds of normal range data. The dotted circles represent the laser residuals to an orbit determined by integrated ranges from the same 20 second time span. The integrated ranges were then smoothed, and the third trace represents the laser residuals to the smoothed CSP ranges.

In conclusion, the above data demonstrate the utility, accuracy, and precision of CSP range-rate measurements. Furthermore, the advantages of precision range-rate for solution of high order terms, such as velocity or acceleration, has been shown.

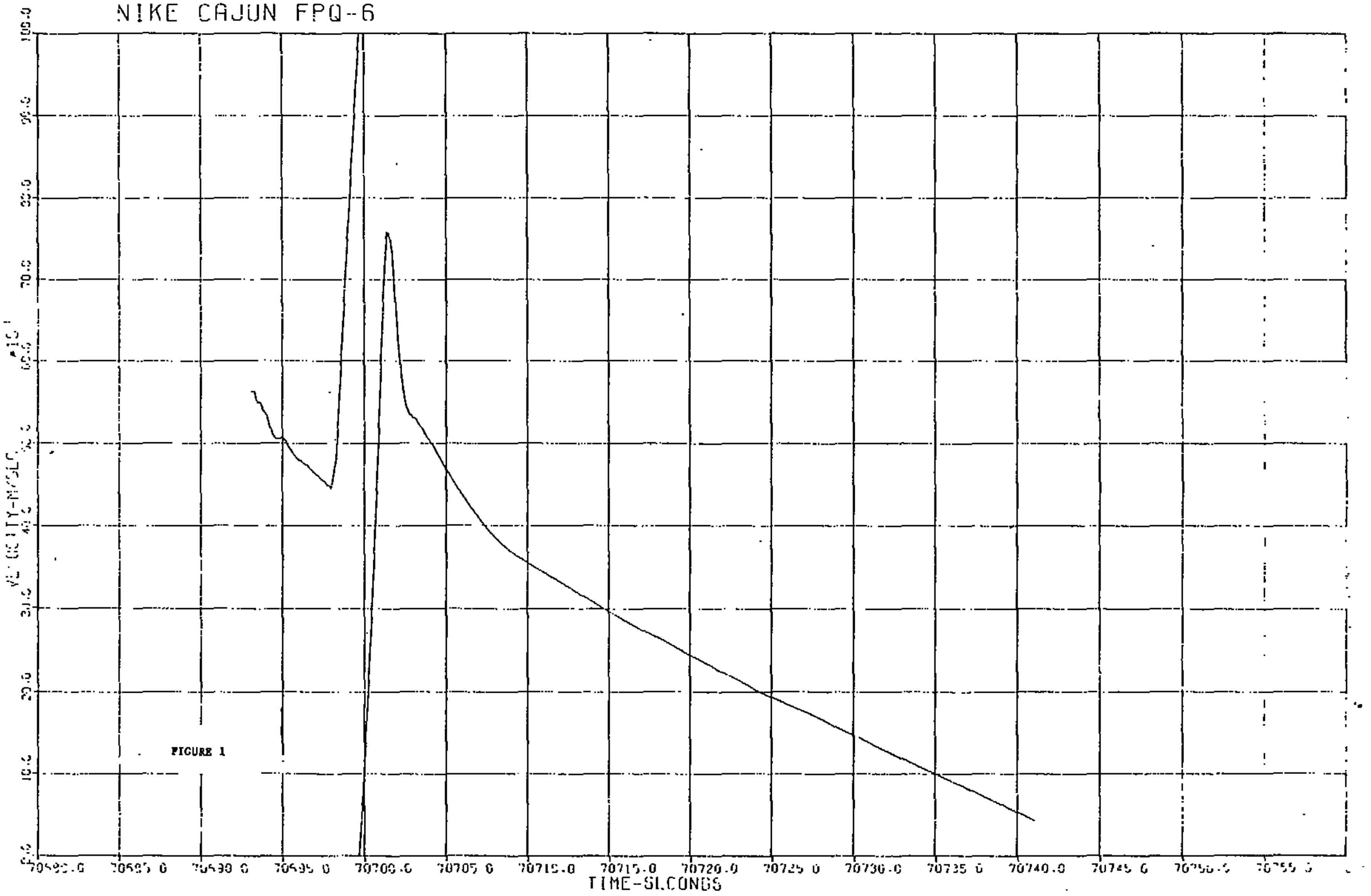
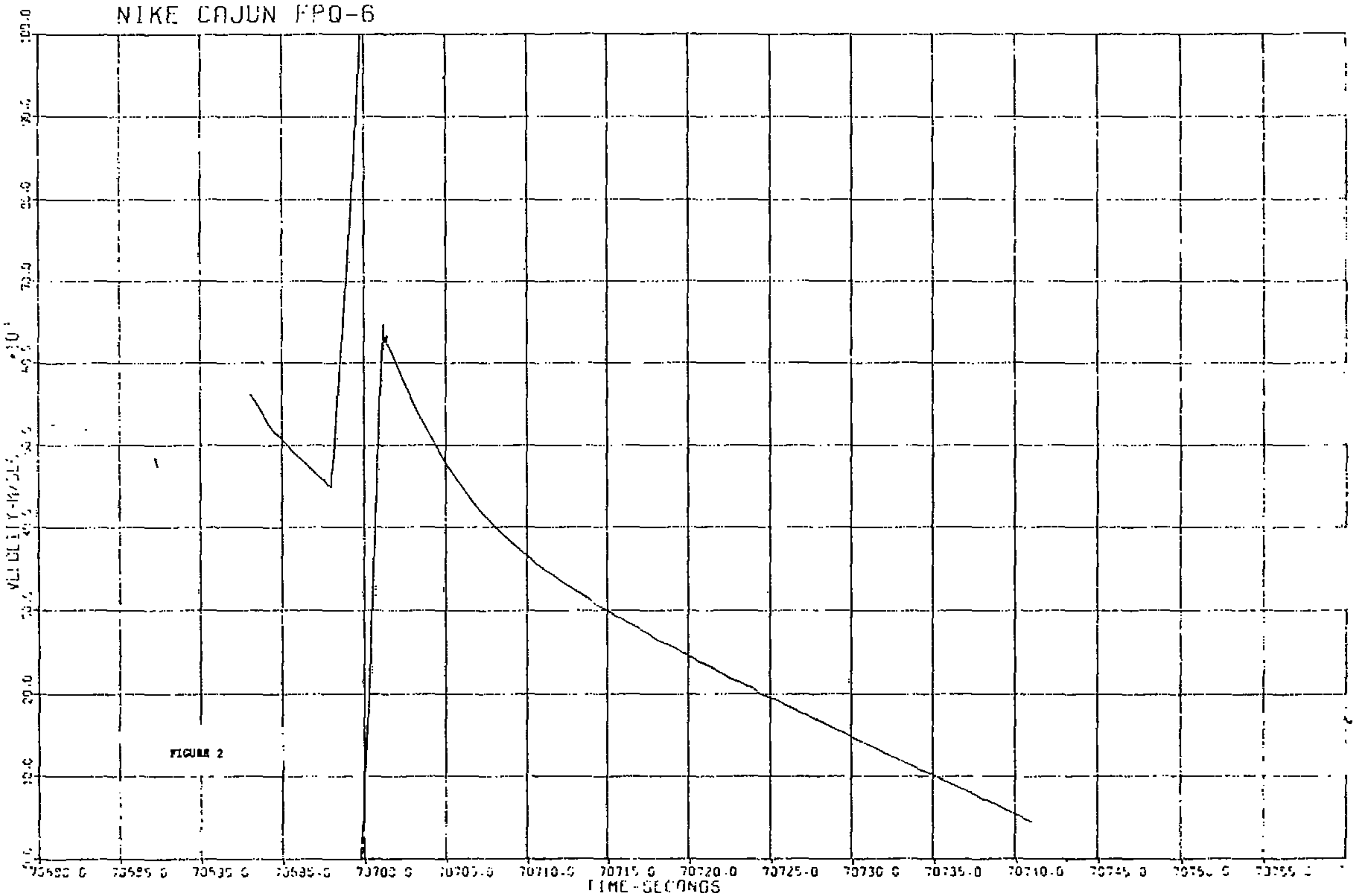

NIKE CAJUN FPQ-6
VELOCITY-M/SEC
*10 1
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
70680.0
70685.0
70690.0
70695.0
70700.0
70705.0
70710.0
70715.0
70720.0
70725.0
70730.0
70735.0
70740.0
70745.0
70750.0
70755.0
TIME-SECONDS

FIGURE 1


NIKE CAJUN FPO-6
VELOCITY-M/SEC
*10¹
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10.0
20.0
30.0
40.0
50.0
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80.0
90.0
100.0
TIME-SECONDS
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70685.0
70690.0
70695.0
70700.0
70705.0
70710.0
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70750.0
70755.0

FIGURE 2

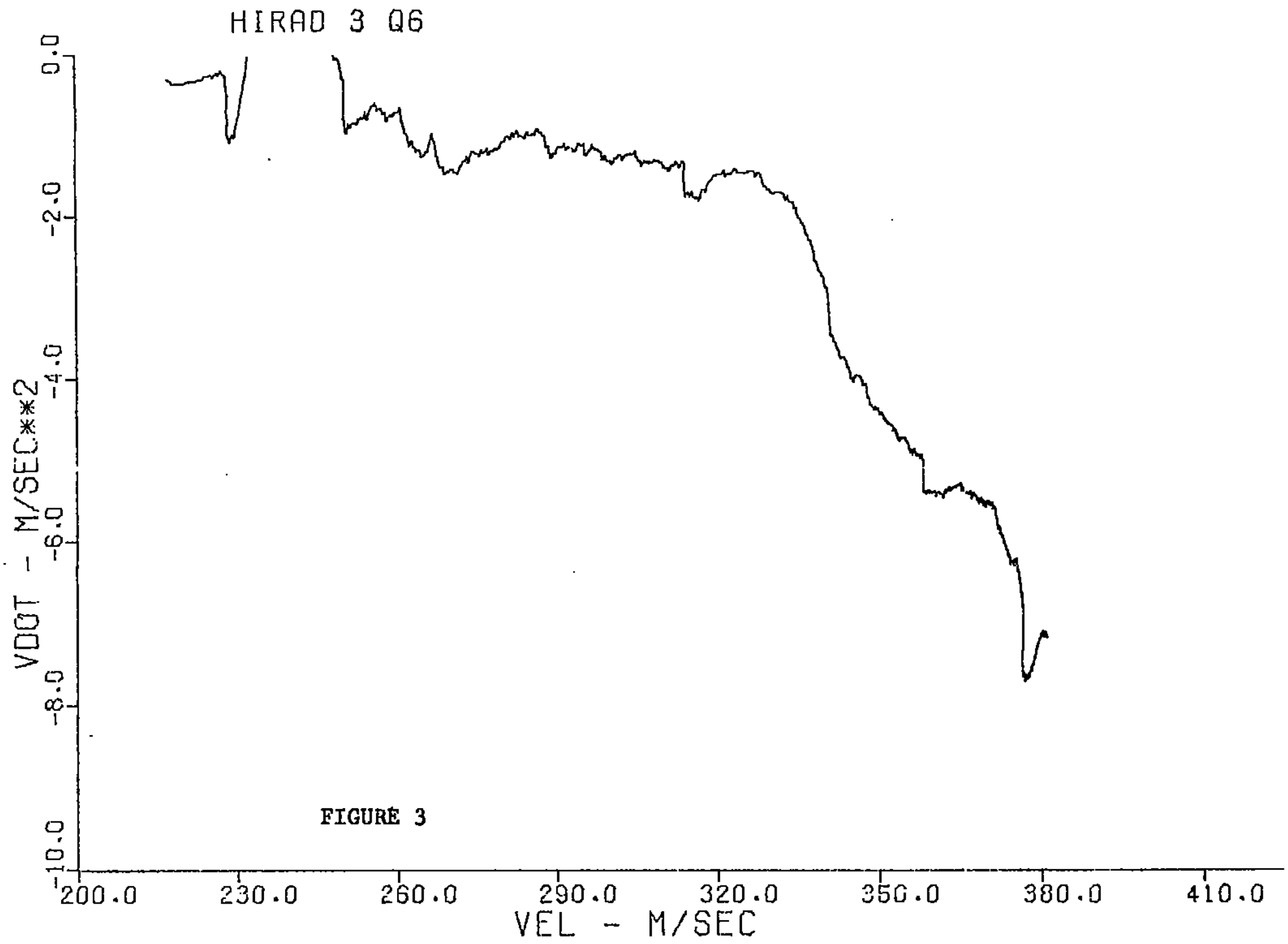

HIRAD 3 Q6
VDOT - M/SEC**2
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
200.0
230.0
260.0
290.0
320.0
350.0
380.0
410.0
VEL - M/SEC

FIGURE 3

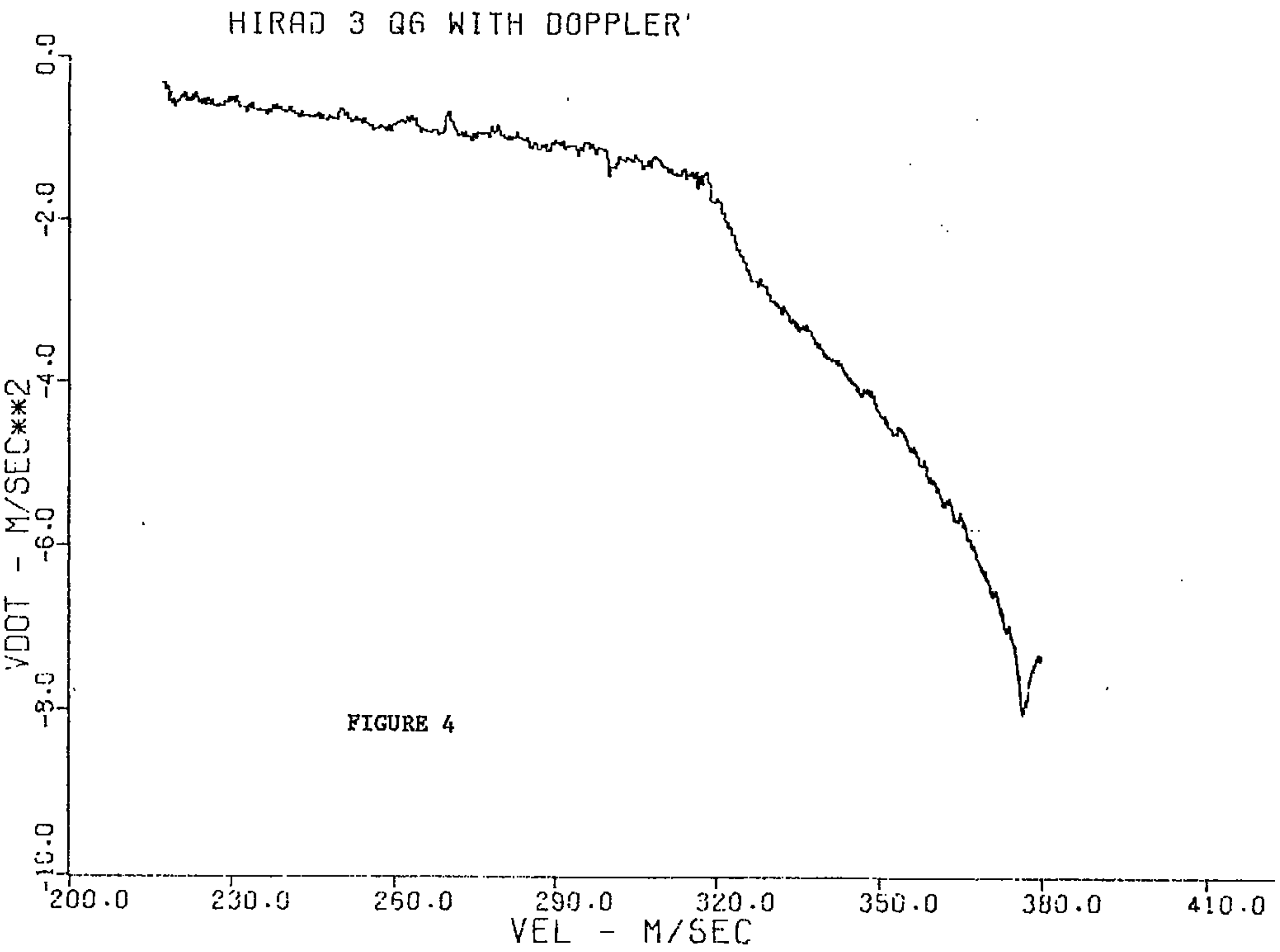

HIRAD 3 Q6 WITH DOPPLER'
VDOT - M/SEC**2
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
VEL - M/SEC
200.0
230.0
260.0
290.0
320.0
350.0
380.0
410.0

FIGURE 4

HIRAD 3 FPQ-6 WITH DOPPLER

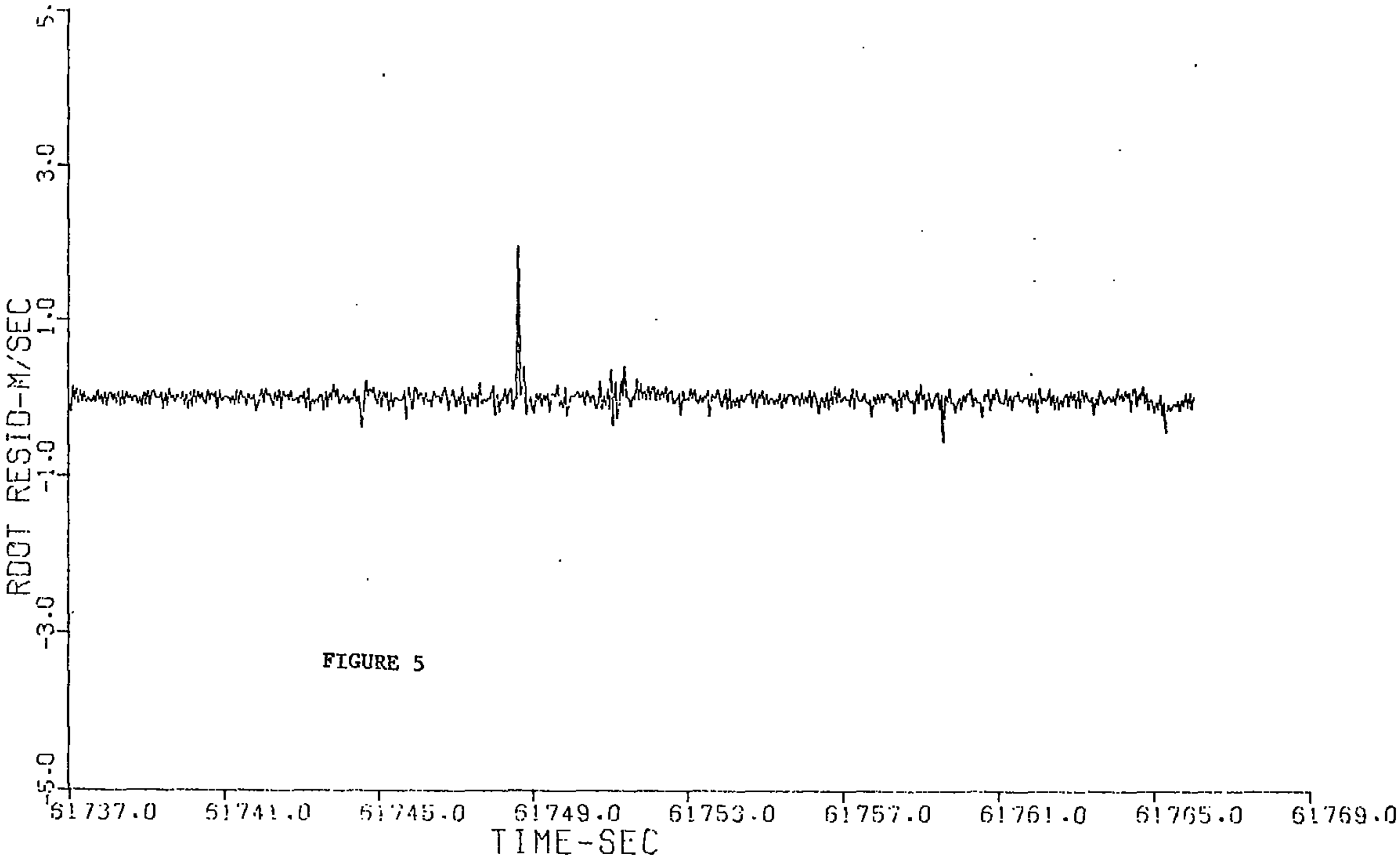
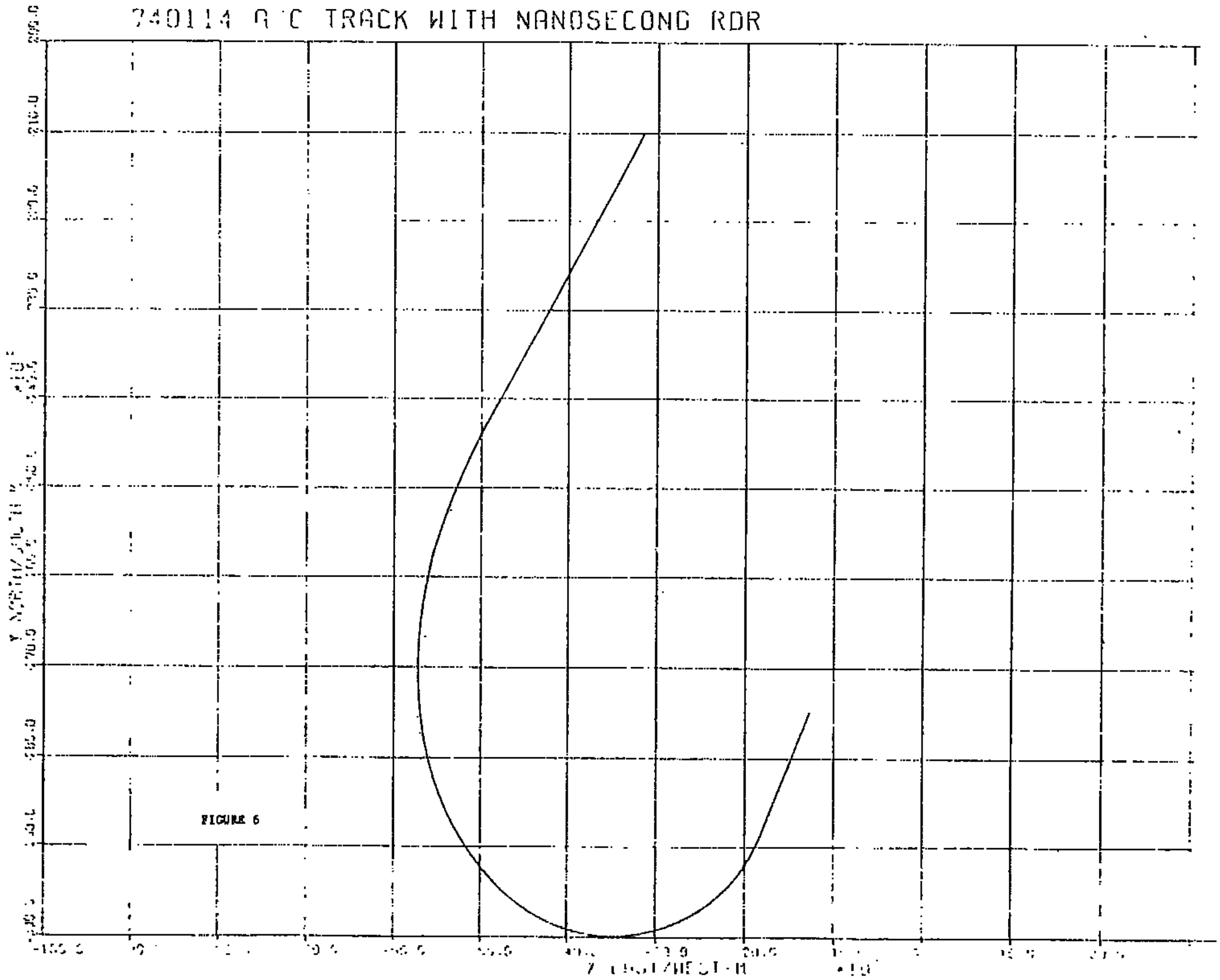


FIGURE 5



740114 A/C TRACK WITH NANOSECOND RDR

FIGURE 6

740114 A/C TRACK WITH NANOSECOND RDR

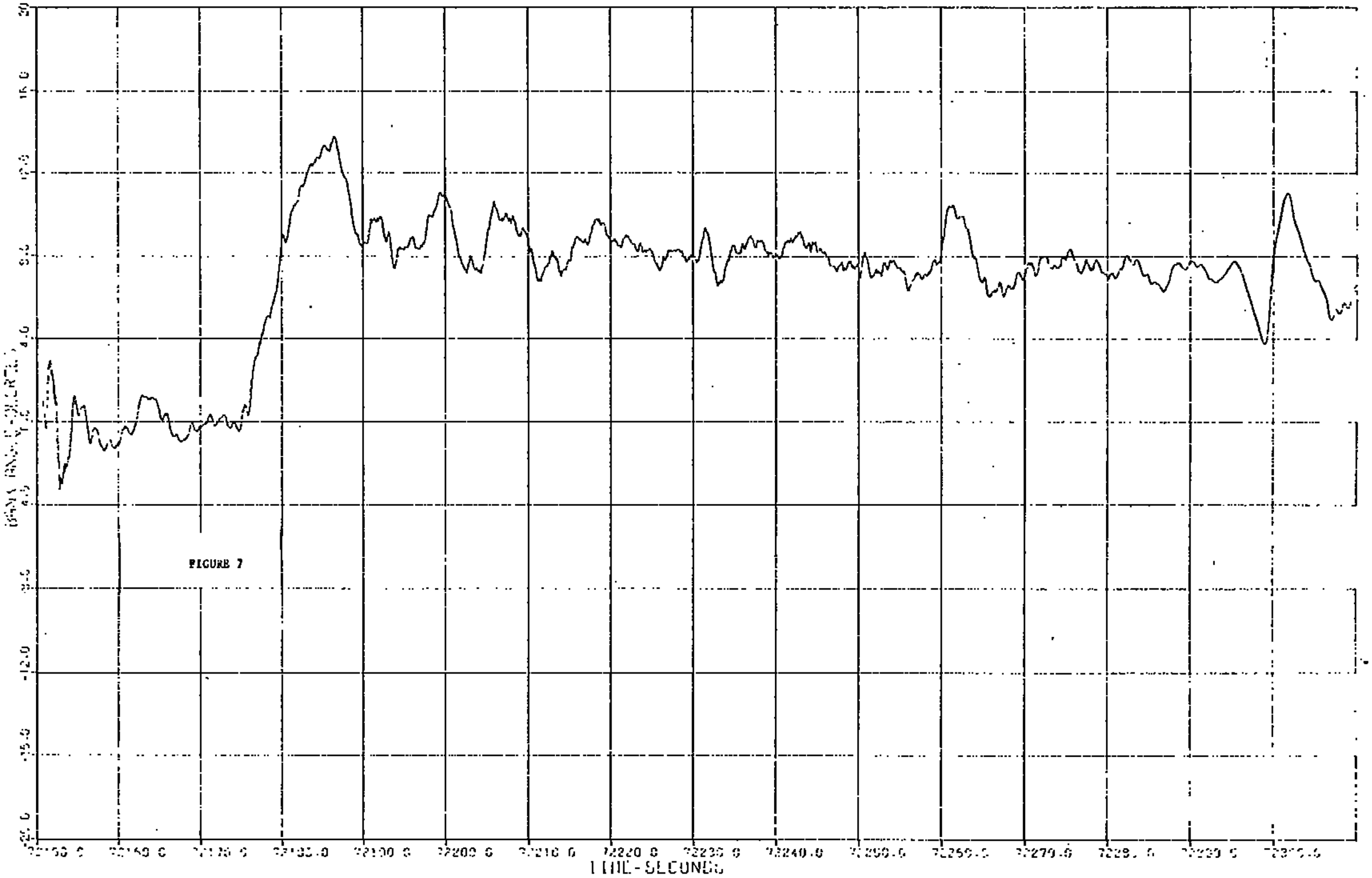


FIGURE 7

740114 A/C TRACK WITH NANOSECOND RDR

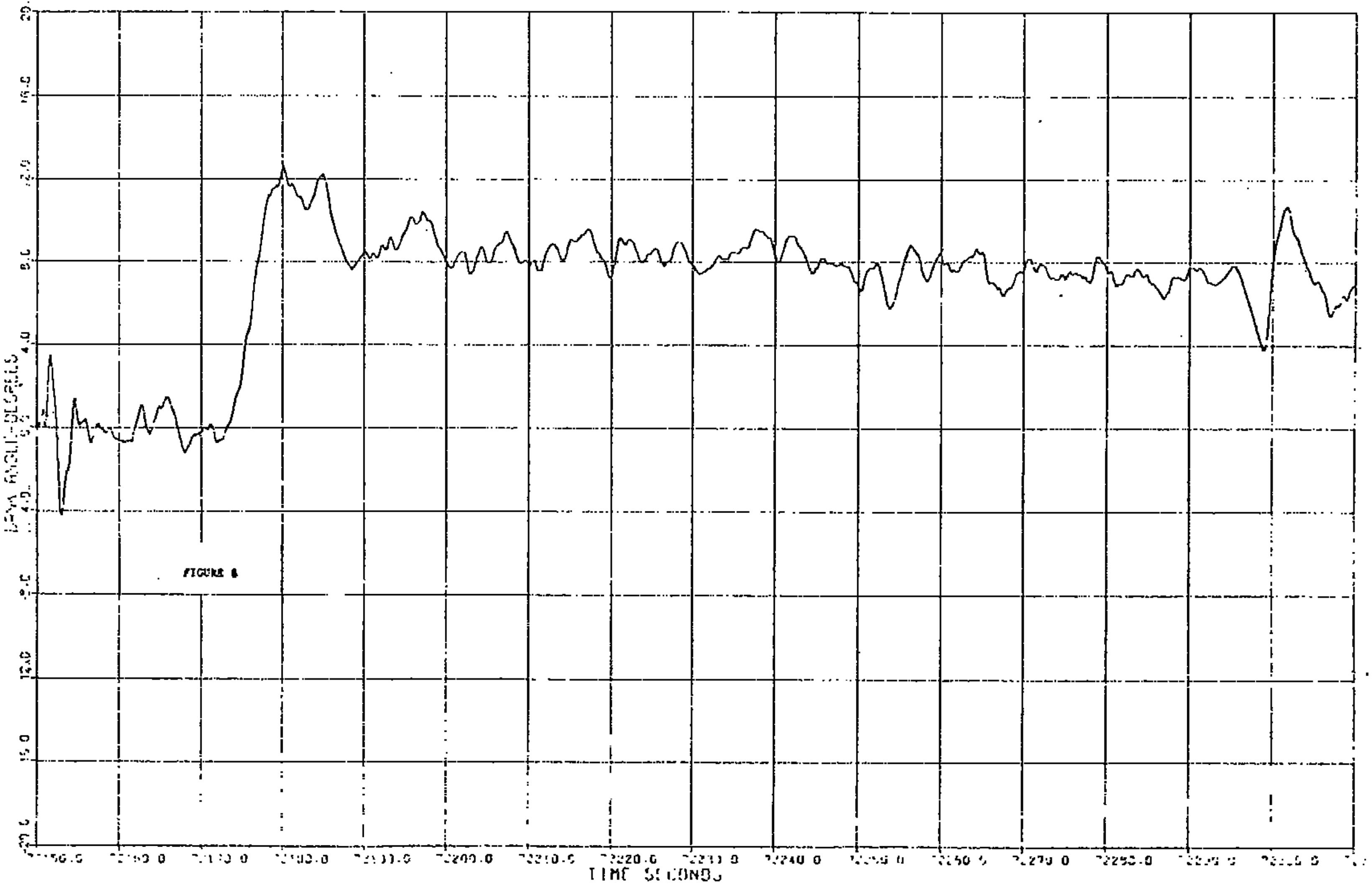


FIGURE 6

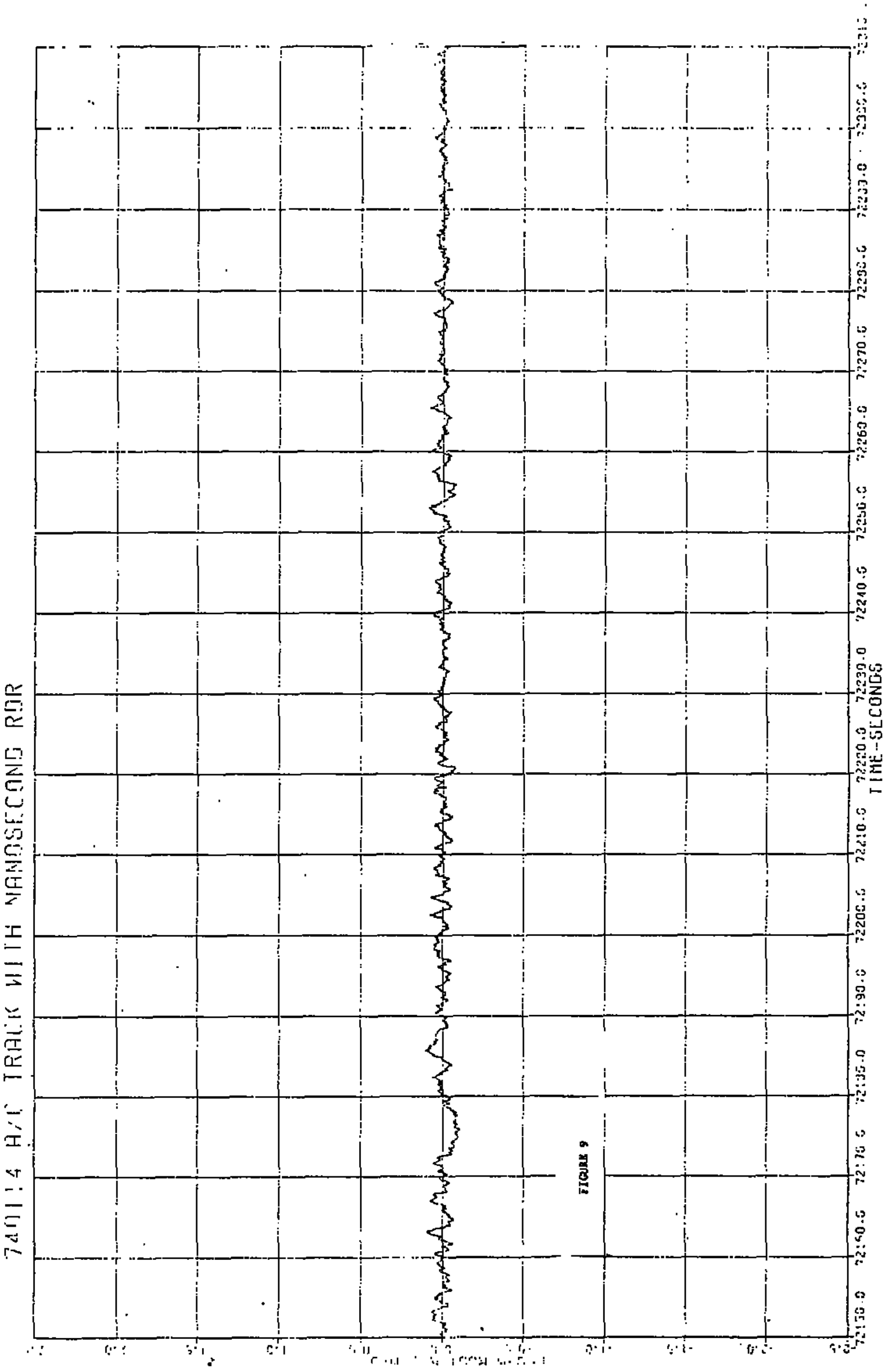

740114 A/C TRACK WITH NANOSECOND RDR
TIME-SECONDS
72150.0
72160.0
72170.0
72180.0
72190.0
72200.0
72210.0
72220.0
72230.0
72240.0
72250.0
72260.0
72270.0
72280.0
72290.0
72300.0
0.0

FIGURE 9

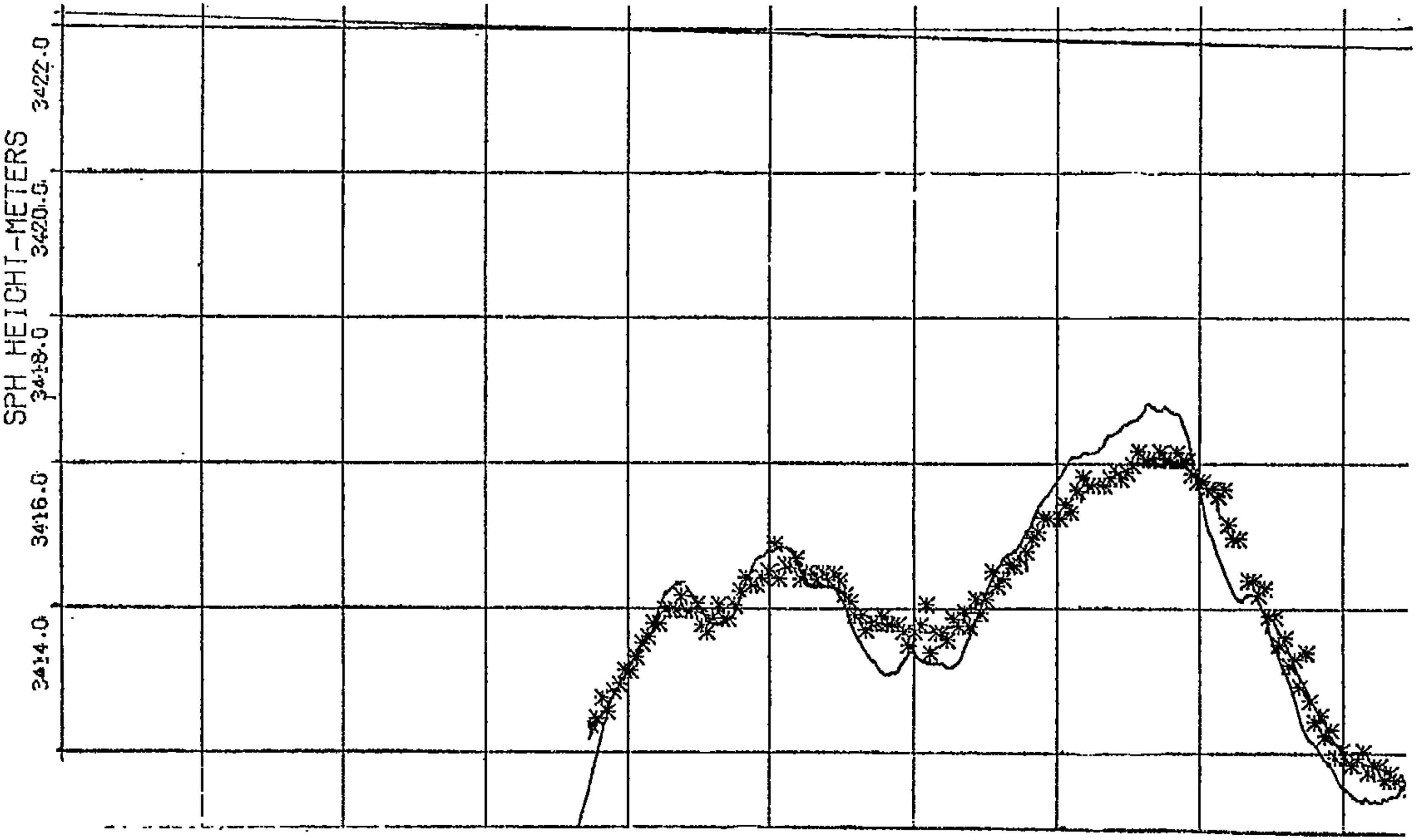
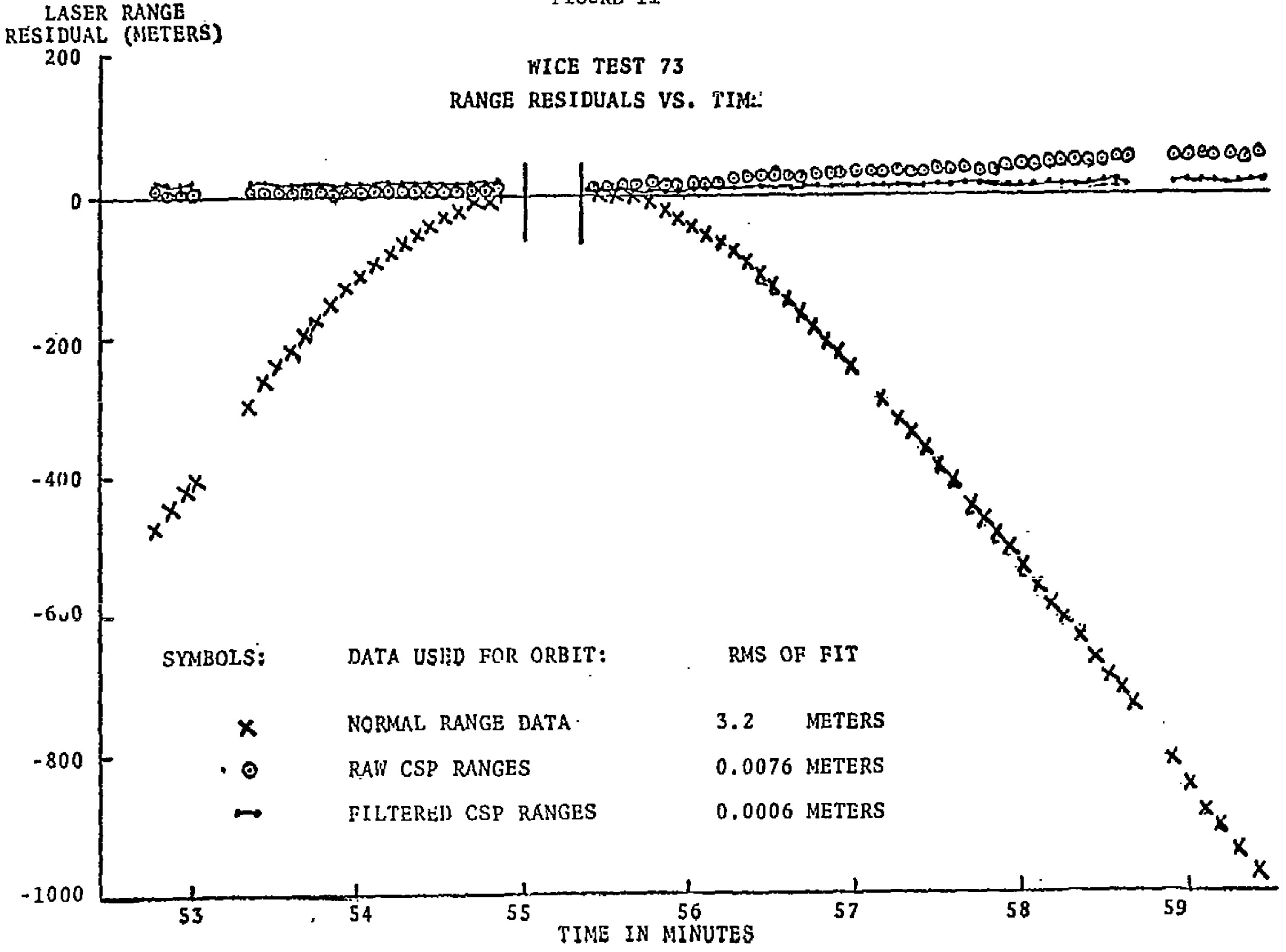


FIGURE 10

FIGURE 11

WICE TEST 73

RANGE RESIDUALS VS. TIME



APPENDIX D

C-BAND AND TRANET TRACKING BIASES RELATIVE TO A COLLOCATED LASER

By

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ABSTRACT

C-BAND AND TRANET TRACKING BIASES RELATIVE TO A COLLOCATED LASER

D. V. Carney
H. C. Parker
J. H. Berbert

As part of the GEOS-II Observation Systems Intercomparison Investigation, the Wallops Island Collocation Experiment (WICE) was conducted during April through June 1968. Among the collocated tracking systems were a NASA laser and an AN/FPQ-6 C-band radar equipped with a coherent signal processor (CSP). The FPQ-6 tracked GEOS both in a beacon mode and in a skin tracking mode. During four of the skin track segments, C-band doppler data was successfully taken and recorded for analysis.

The laser data were used to form reference orbits against which the doppler data were compared with the NONAME orbit determination program. Simple error models, consisting of measurement and timing bias terms, were then fit to the data. The RMS noise of the residuals varied from 2.7 cm/sec to 13.3 cm/sec, and the derived range rate measurement bias varied from -1.3 ± 0.5 cm/sec to 6.7 ± 0.7 cm/sec with an average value of 2.5 cm/sec. The timing bias ranged from 0.01 ± 0.20 milliseconds to 0.45 ± 0.20 milliseconds.

1.1 INTRODUCTION

The GEOS-II Observation Systems Intercomparison Investigation was designed to evaluate the relative accuracies of various geodetic observation systems. As a part of this effort, the Wallops Island Collocation Experiment (WICE) (Reference 1) was conducted during the period of April through June 1968. A NASA laser, two C-band radars (an AN/FPQ-6 and an AN/FPS-16), several cameras, a Navy TRANET doppler, and an Army SECOR comprised the tracking systems employed. These trackers were collocated with one another in order to minimize relative station survey errors (determined to better than 10 cm.) and earth gravity field errors that might otherwise be aliased into tracking biases. The NASA laser range, azimuth, and elevation (RAE) data were weighted at 2 meters, 200 arc seconds, and 200 arc seconds, respectively, and were used to form the reference orbits against which the other systems were compared.

The AN/FPQ-6 C-band radar used a coherent signal processor (CSP) to provide doppler range rate measurements on GEOS-II during the WICE (References 2 and 3). However, since GEOS did not have a coherent beacon, the CSP could only be used during a skin track. The skin tracks were augmented by a Van Atta retroreflector array on the GEOS spacecraft. Of the 34 FPQ-6 tracks simultaneous with the laser, 10 were taken both in the beacon and skin track modes. For those 10 passes, the FPQ-6 was calibrated for the skin track portion, tracked the first third of the pass with the beacon, was switched to skin track for the second third of the pass, and back to the beacon for the final third. Doppler tracking was attempted during nine passes, successfully on eight of the nine. Of the eight, the four for which we received data (on May 30, June 5, June 11 and June 12) are covered in this report.

1.2 SOFTWARE

The FPQ-6 doppler data forwarded to us from Wallops Station were known to contain a hardware truncation error with a maximum value of 2.8575 cm/sec. Similarly, the zero-set bias correction normally measured at Wallops had not been applied or recorded (Reference 4). Neither of these errors were recoverable. The data, as received, were corrected for a known error in the speed of light constant representation which existed in the radar hardware system at that time (Reference 5) and were preprocessed with the RCA C-band Pre-processing Program (Reference 6) for time tag and tropospheric refraction corrections.

As in the WICE report (Reference 1), the NONAME Orbit Determination Program (ODP) (Reference 7) was used to reduce the laser RAE data through a least squares fit procedure to form the reference orbits against which the FPQ-6 and TRANET range rate data were compared. Simple error models for measurement bias and timing bias were then fit to the range rate residuals with the ODP.

1.3 A PRIORI DATA AND ERROR MODEL WEIGHTINGS

For the purposes of this report, a specific error model is defined as any distinct combination of bias uncertainty terms and the values assigned to those terms, i.e., different value combinations for the bias uncertainty terms create different error models.

Of the four available passes, two were simultaneous with TRANET doppler data, on June 11 and June 12. Previous analyses of the TRANET data have established appropriate weightings for that data and confidence in the results. It was determined that, due to the fairly high correlation of the range rate bias to the timing bias, the TRANET time bias had to be constrained to 0.2 milliseconds (ms) in order to get reasonable estimates of the measurement bias. However, the first FPQ-6 error model allowed an increase to 1 millisecond in the a priori timing uncertainty in an attempt to estimate the relatively unknown timing bias for the new C-band doppler data. Since reasonable estimates of the timing and measurement bias were not recovered, it was again assumed that due to the accuracies of the collocation techniques, the relative timing bias was as accurate as that of the TRANET. Thus, in the second error model, the a priori FPQ-6 timing uncertainty was reduced to 0.2 milliseconds, matching the TRANET error model terms.

The first two rows of Table I give the a priori weights (SIGMA) assigned to the laser measurements used to form the reference orbits. The third row indicates the SIGMA applied to the FPQ-6 range rate data in the unmodeled runs for each of the four passes. For both remaining stations, the columns show the error model number, the SIGMA, the initial estimate of the measurement bias (BIAS), the uncertainty about that measurement bias (BIAS SIGMA), the initial estimate of the measurement timing bias (TIME BIAS), and the uncertainty about that time bias (TIME SIGMA). Error model 1 was used in the original analyses of the FPQ-6 range rate data; models 2 and 3 came from the WICE TRANET error modeling study.

In all of the error model recovery runs, the laser reference orbit was held fixed by weighting the position and velocity state vector components at 10^{-6} meters and 10^{-12} meters per second, respectively, thus forcing the error model coefficients to fit the C-band residuals.

2.1 RESULTS

Figure I is a display of the plots of the unmodeled range rate residuals against the laser RAE reference orbits for each of the four passes. Each plot shows the FPQ-6 residuals sampled every five seconds and the time-location of the doppler skin track portion within the laser pass. None of the FPQ-6 range rate initial points are coincident with the first range point of the skin track; rather, the range rate data starts later by 58, 65, 79 and 109 seconds, respectively, for the four passes taken in chronological order. Further, the point of the closest approach (PCA) of the satellite consistently occurs at the second time point of each range rate track and lies between 71° and 88° elevation.

The lower two plots, i.e., the June 11 and 12 passes, also show the unmodeled TRANET residuals for comparison. These data were smoothed over a 32-second interval during the Naval Weapons Laboratory (NWL) preprocessing and are shown without further sampling.

Figure II illustrates the residuals as they appear after the second error model was applied during both the FPQ-6 and TRANET data reductions.

Table II summarizes the pass statistics for the residuals and the derived measurement and timing bias error model terms for the four FPQ-6 tracks and the two simultaneous TRANET tracks. The RMS noise values are given for both the first and final iterations to show the effective noise reduction resulting from modeling the systematic trends within each pass. The mean value of the residuals for iteration one is given for comparison to the measurement bias term derived in subsequent iterations, when the residual mean has been reduced to zero. When both the biases and their associated uncertainties are considered, the best results appear to be obtained with the second error model.

The third error model was used in an attempt to display the effects caused by assuming the measurement bias to be fairly well known and the timing bias relatively unknown.

Table III is a summary of the statistics for each item of interest averaged over the four FPQ-6 passes, the two simultaneous passes of the low frequency TRANET pair (Lo), and finally, for reference, over the 26 passes of the low and the 16 passes of the high-frequency TRANET pairs taken during the WICE.

It has been shown in a separate set of runs not given here, that when no time bias error term is solved for, the derived measurement bias for the final iteration is equal to the residual mean value from the first iteration. The measurement errors are forced into the range rate bias with a slight degradation (0.0 to 0.1 cm/sec.) in the RMS noise; i.e., if a timing bias does indeed exist, it can be aliased into a measurement bias with an appropriate error model. Conversely, if no measurement bias term is allowed and the time bias uncertainty is set large at ± 1 second, the residual mean values are reduced to a near-zero level. The time bias term will now absorb most of the measurement error, varying from -0.30 milliseconds to 2.51 milliseconds. This indicates that the range rate and timing biases are highly correlated and points out the need to assign relative uncertainties which approximate reality. Due to the careful relative time synchronization techniques, we believe that the clocks were indeed synchronized to at least 200 μsecs. (0.2 millisec.), as used in error model 2.

The C-band doppler tracks are all one-sided, starting a few seconds before PCA and then continuing down to an elevation of between 45° and 60°. The doppler data were offset from the start of the skin track due to difficulties in "locking on" for range rate. Had the passes been more nearly symmetrical, the bias terms should have been more separable.

Figure III consists of two overlays of the FPQ-6 range rate biases on plots of the WICE TRANET measurement biases. In both cases, the TRANET range rate biases were derived with the second error model. The first (top) plot shows the FPQ-6 biases as they were originally derived with the first error model (Reference 8). The second (bottom) plot compares the FPQ-6 biases as derived with the second model to the TRANET biases. It is apparent that the more realistic second model yields FPQ-6 measurement biases that generally agree more closely with the laser reference orbit and the TRANET than does the first model.

Figure IV is an overlay of the FPQ-6 skin track range biases on plots of the FPQ-6 beacon mode, the FPS-16 C-band, and the SECOR range biases from the WICE. It is included as supplementary information, showing the degree of aggreement between the ranging biases for the skin track portion (X) and the beacon track portion (∇) with the laser reference orbit and the other systems during that period.

It has been reported (Reference 9) that the phase center of the TRANET antenna was on the order of 1 meter different from the geometric antenna center that we have been using. Runs were made for the June 11 and June 12 TRANET passes using the modified phase center coordinates. The measurement biases recovered using error model 2 deviated from the previous results by less than 0.4 cm/sec. The timing biases did not change.

3.1 CONCLUSIONS

While it is understood that, due to the sparse number of passes, these results are not very conclusive, they are an indication of what was achieved in early GEOS-II attempts to utilize CSP doppler data available from the Wallops AN/FPQ-6 radar operating in a skin track mode. The data in this study is somewhat corrupted with non-recorded zero-set and truncation errors, yet the results appear reasonable for a C-band range rate system at that time, particularly for the last (6/12) pass.

Considering error model 2, the FPQ-6 range rate biases range from -1.3 cm/sec to 6.7 cm/sec with timing biases of 0.01 milliseconds to 0.45 milliseconds. For the two simultaneous TRANET passes, the range rate biases are 1.9 cm/sec and 1.2 cm/sec with timing biases of 0.00 ms. and 0.05 ms.

The measurement range rate bias results are significantly better with less uncertainty when the time bias term is more tightly constrained (from 1 second, or 1 millisecond, down to 0.2 millisecond uncertainty), indicating that, due to the correlation between the range rate and timing bias coefficients, it is important to use realistic time bias constraints. By using the more realistic estimate of the uncertainty in the FPQ-6 clock, the results are substantially improved over previous analyses.

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TABLE I

A PRIORI DATA AND ERROR MODEL TERM WEIGHTS

Station	Meas. Type	Units	Error Model	Sigma	Bias	Bias Sigma	Time Bias (secs)	Time Sigma (secs)
Laser	Range	meters	Reference Orbits	2.0	—	—	—	—
Laser	Az/El	arc secs.		200.0	—	—	—	—
FPQ-6	R. Rate	m/sec.	Unmodeled	0.04	—	—	—	—
FPQ-6	R. Rate	m/sec.	1	0.04	0.0	10.0	0.0	0.0010
FPQ-6	R. Rate	m/sec.	2	0.04	0.0	10.0	0.0	0.0002
FPQ-6	R. Rate	m/sec.	3	0.04	0.0	0.08	0.0	1.0
TRANET	R. Rate	m/sec.	1	0.04	0.0	10.0	0.0	0.0010
TRANET	R. Rate	m/sec.	2	0.04	0.0	10.0	0.0	0.0002
TRANET	R. Rate	m/sec.	3	0.04	0.0	0.08	0.0	1.0

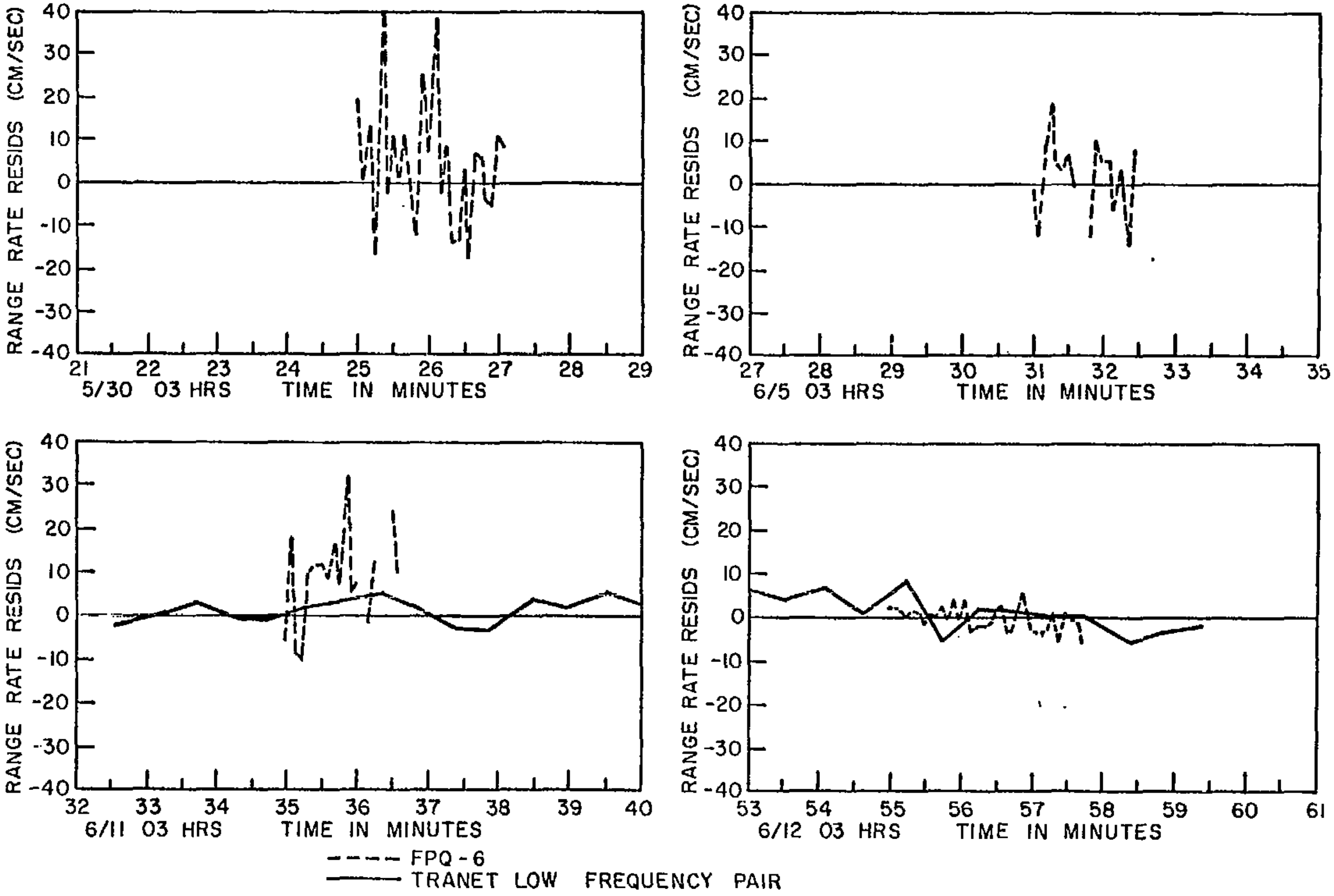


FIGURE I. UNMODELED FPQ-6 AND TRANET RANGE RATE RESIDUALS VS TIME

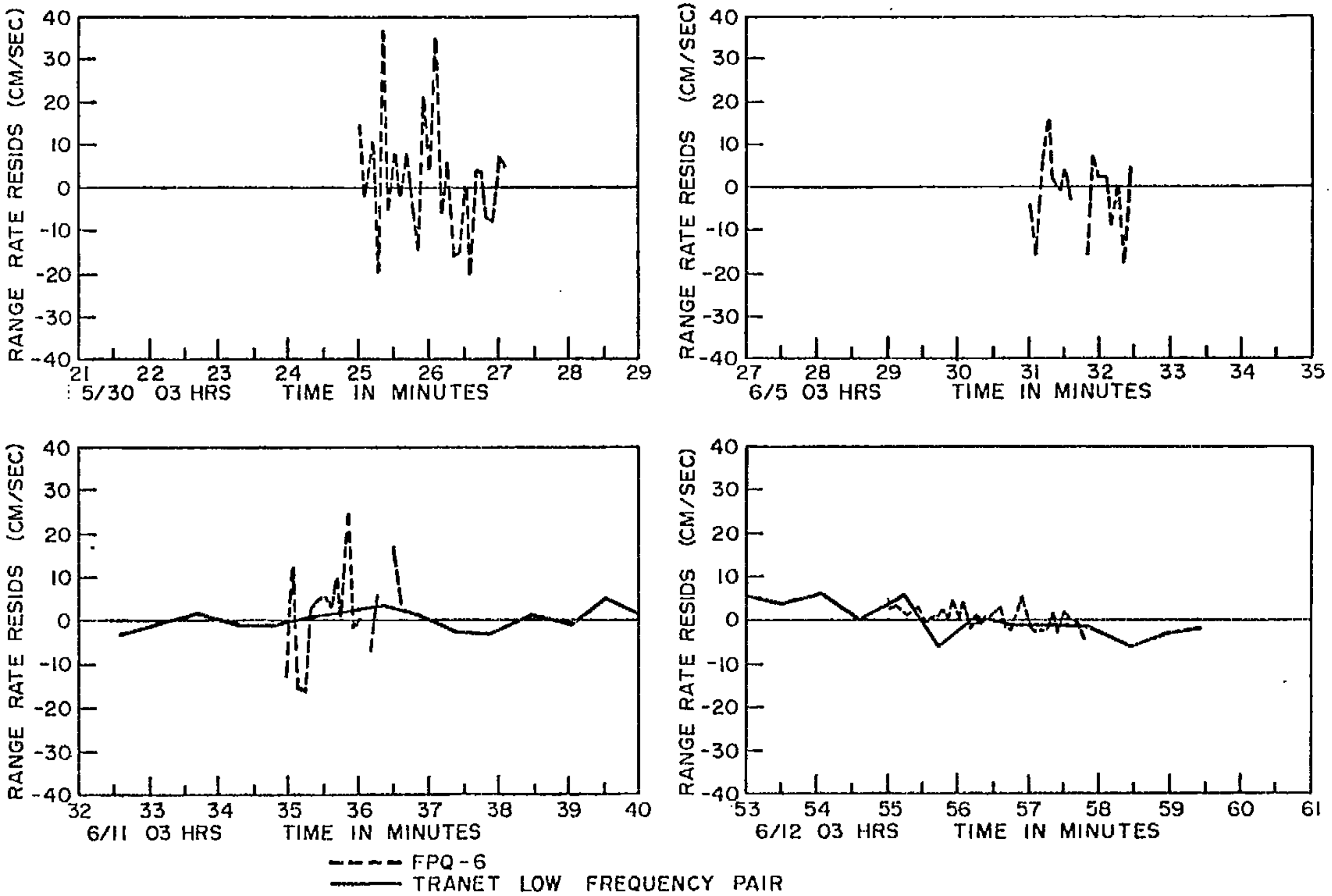


FIGURE II. ERROR MODEL 2, FPQ-6 AND TRANET RANGE RATE RESIDUAL VS TIME

TABLE II

FPQ-6 AND TRANET RANGE RATE RESIDUAL STATISTICS AND BIAS VALUES

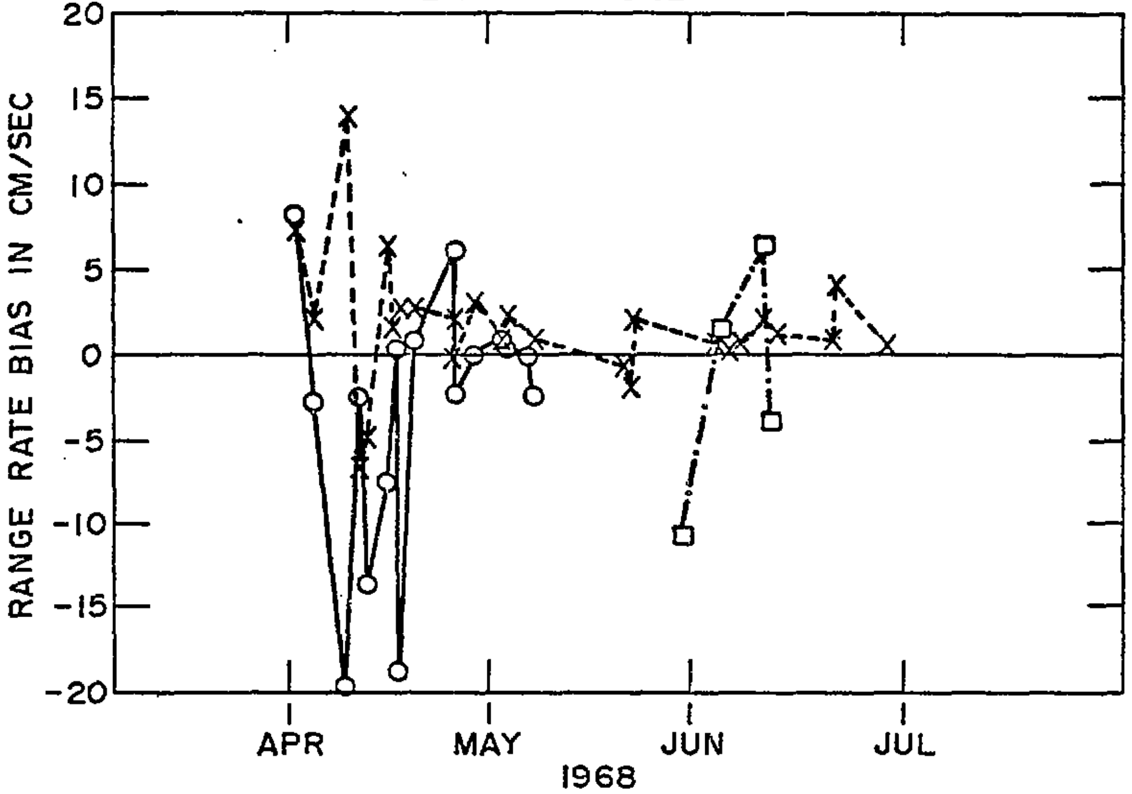
Station	Model	Epoch	RMS		Mean	Bias	Time Bias
			Iter. 1 (cm/sec)	Iter. 3 (cm/sec)	Iter. 1 (cm/sec)	Value Sigma (cm/sec)	Value Sigma (millisec)
FPQ-6	Unmodeled	5/30	13.7	13.7	3.2	—	—
		6/5	12.9	12.9	2.5	—	—
		6/11	12.6	12.6	6.7	—	—
		6/12	2.9	2.9	-0.9	—	—
FPQ-6	1	5/30	13.7	12.9	3.2	-10.9 ± 1.8	5.17 ± 0.66
		6/5	12.9	12.6	2.5	1.2 ± 2.6	0.46 ± 0.92
		6/11	12.6	10.7	6.7	6.2 ± 2.5	0.17 ± 0.92
		6/12	2.9	2.5	-0.9	-4.2 ± 1.3	1.40 ± 0.53
FPQ-6	2	5/30	13.7	13.3	3.2	2.0 ± 0.6	0.45 ± 0.20
		6/5	12.9	12.6	2.5	2.5 ± 0.7	0.02 ± 0.20
		6/11	12.6	10.7	6.7	6.7 ± 0.7	0.01 ± 0.20
		6/12	2.9	2.7	-0.9	-1.3 ± 0.5	0.18 ± 0.19
FPQ-6	3	5/30	13.7	12.8	3.2	-19.8 ± 2.3	8.48 ± 0.84
		6/5	12.9	12.6	2.5	-3.3 ± 5.0	2.09 ± 1.78
		6/11	12.6	10.7	6.7	2.2 ± 5.0	1.68 ± 1.87
		6/12	2.9	2.5	-0.9	-5.3 ± 1.5	1.88 ± 0.62
TRANET	Unmodeled	6/11	3.2	3.2	1.9	—	—
		6/12	4.6	4.6	1.3	—	—
TRANET	1	6/11	3.2	2.6	1.9	1.9 ± 2.0	-0.02 ± 0.85
		6/12	4.6	4.0	1.3	-0.5 ± 2.0	0.91 ± 0.83
TRANET	2	6/11	3.2	2.6	1.9	1.9 ± 1.1	0.00 ± 0.20
		6/12	4.6	4.3	1.3	1.2 ± 1.2	0.05 ± 0.20
TRANET	3	6/11	3.2	2.6	1.9	1.7 ± 3.0	0.07 ± 1.49
		6/12	4.6	3.7	1.3	-4.0 ± 3.0	2.66 ± 1.40

TABLE III

AVERAGED STATISTICS FOR THE RANGE RATE PASSES

Station	Model	Sample Size	RMS (cm/sec)	Iter. 3 Mean (cm/sec)	Meas. Bias (cm/sec)	Time Bias (millisec)
FPQ-6	Unmodeled	4	10.5 ± 4.4	2.9 ± 2.7	—	—
	1	4	9.7 ± 4.2	—	-1.9 ± 6.4	1.80 ± 2.00
	2	4	9.8 ± 4.2	—	2.4 ± 2.9	0.17 ± 0.18
	3	4	9.7 ± 4.2	—	-6.5 ± 8.1	3.50 ± 2.00
FPQ-6	Unmodeled	2	7.8 ± 4.9	2.9 ± 3.8	—	—
	1	2	6.6 ± 4.1	—	1.0 ± 5.2	0.79 ± 0.62
	2	2	6.7 ± 4.0	—	2.6 ± 4.0	0.10 ± 0.09
	3	2	6.6 ± 4.1	—	-1.5 ± 3.8	1.78 ± 0.10
TRANET (LO)	Unmodeled	2	3.9 ± 0.6	1.6 ± 0.3	—	—
	1	2	3.3 ± 0.7	—	0.7 ± 1.2	0.45 ± 0.47
	2	2	3.5 ± 0.9	—	1.5 ± 0.3	0.01 ± 0.01
	3	2	3.2 ± 0.6	—	1.2 ± 2.9	1.37 ± 1.30
WICE						
TRANET (LO)	2	26	4.5 ± 2.0	—	1.4 ± 3.5	0.00 ± 0.10
TRANET (HI)	2	16	6.1 ± 7.0	—	-3.2 ± 7.5	0.00 ± 0.01

ERROR MODEL 1



ERROR MODEL 2

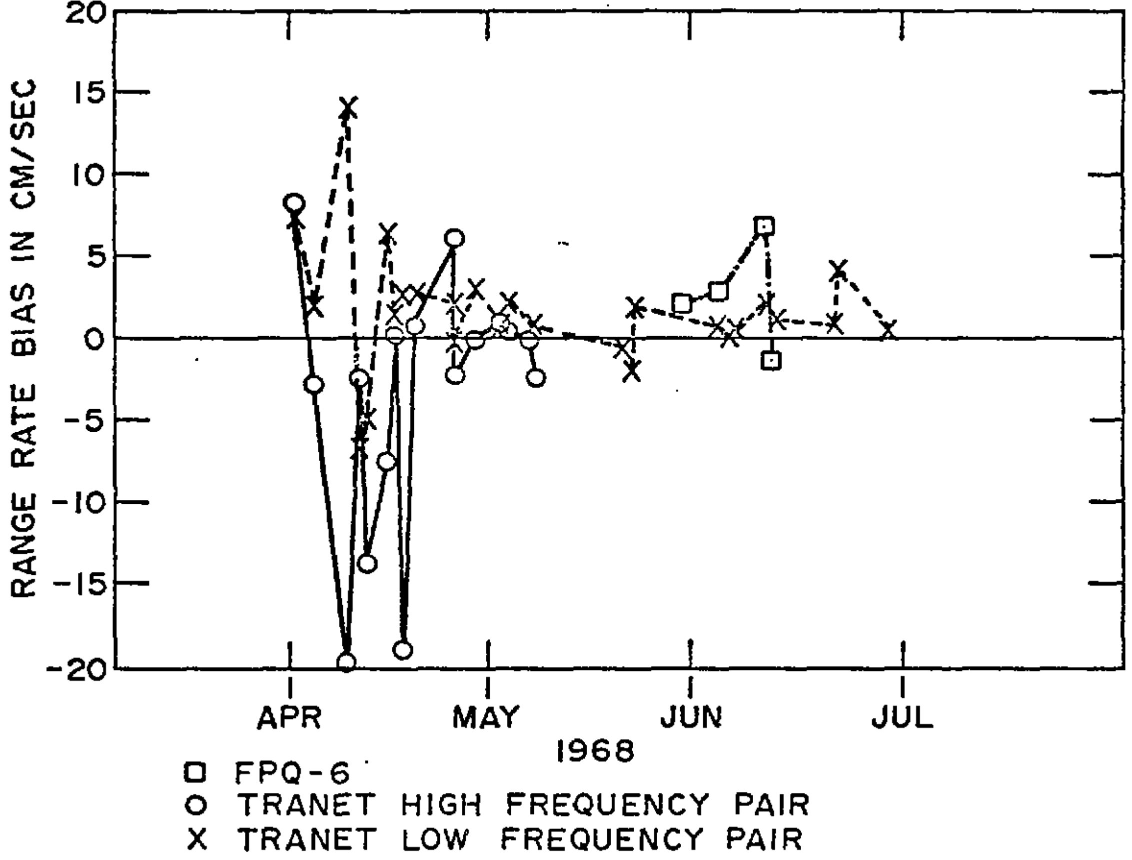
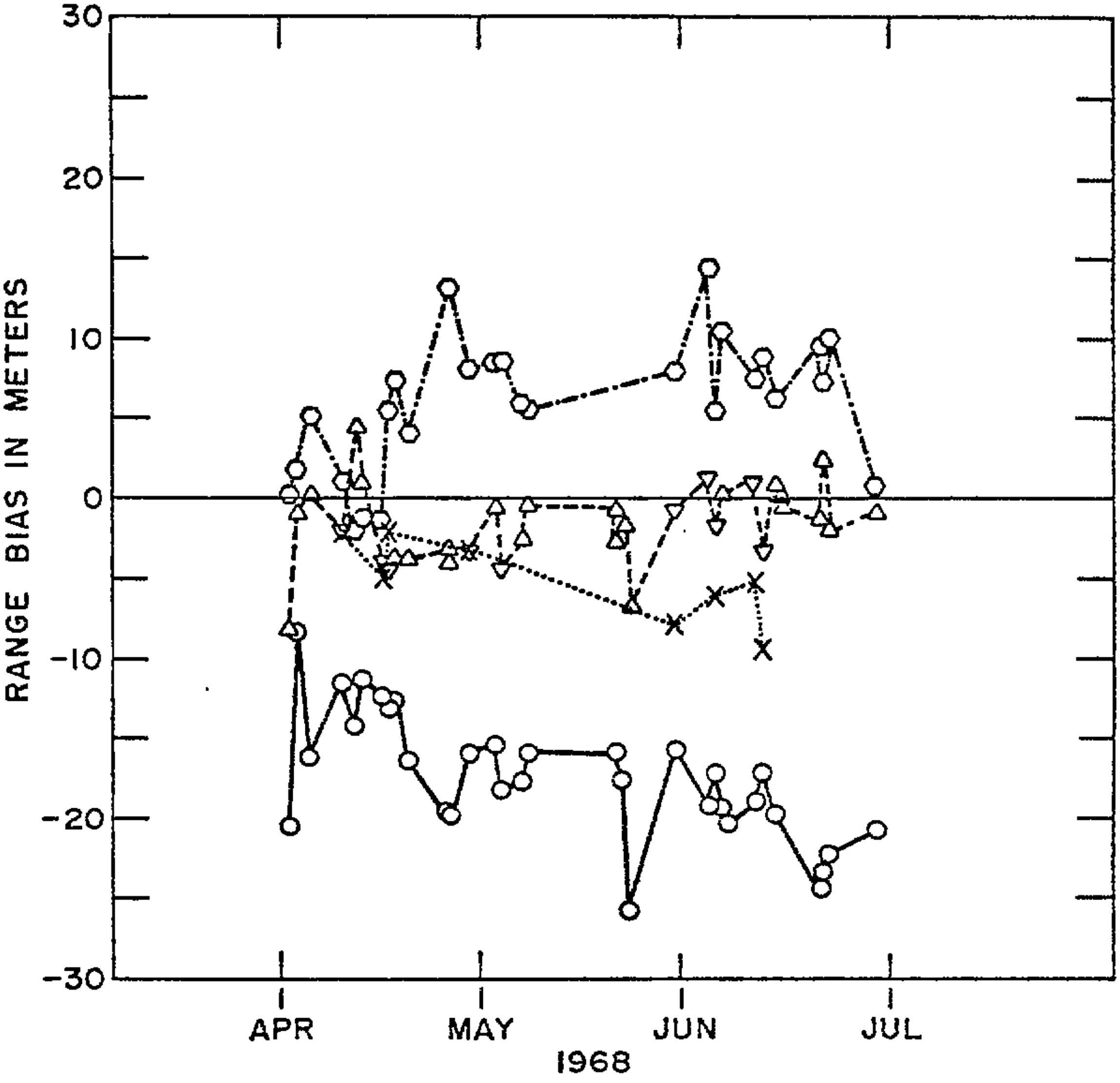


FIGURE III. FPQ-6 AND TRANET RANGE RATE BIASES VS. DATE



○ SECOR

○ FPS-16

△ FPQ-6 (BEACON TRACK)

▽ FPQ-6 (BEACON TRACK SEGMENT)

X FPQ-6 (SKIN TRACK SEGMENT)

FIGURE IV. WICE RANGE BIASES VS. DATE (LASER REFERENCE ORBITS)

APPENDIX E

INFLUENCES OF RANGE-RATE MEASUREMENTS
OF
ICBM INSTANTANEOUS IMPACT PREDICTION ACCURACY

By

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Federal Electric Corporation ITT
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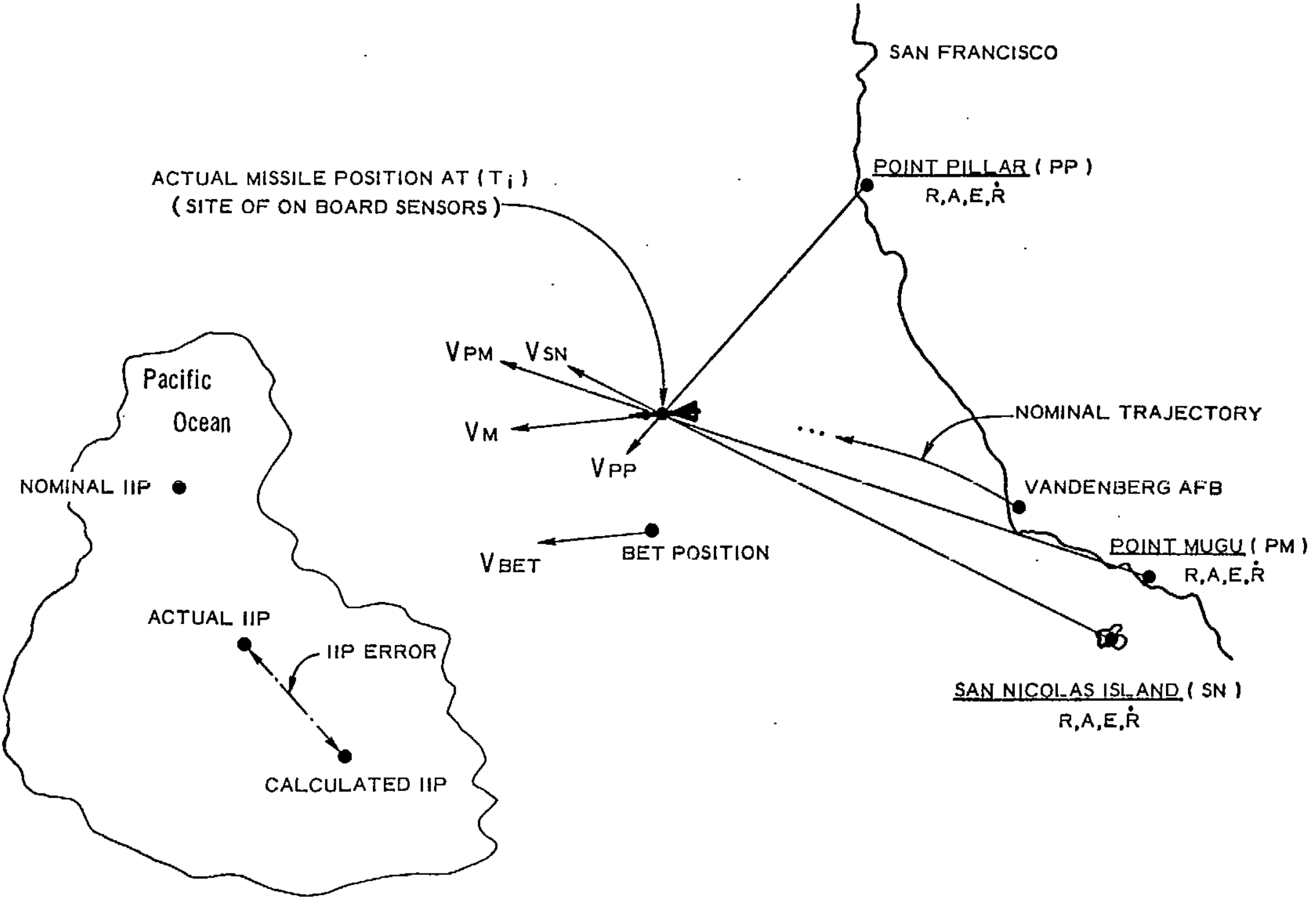
OUTLINE

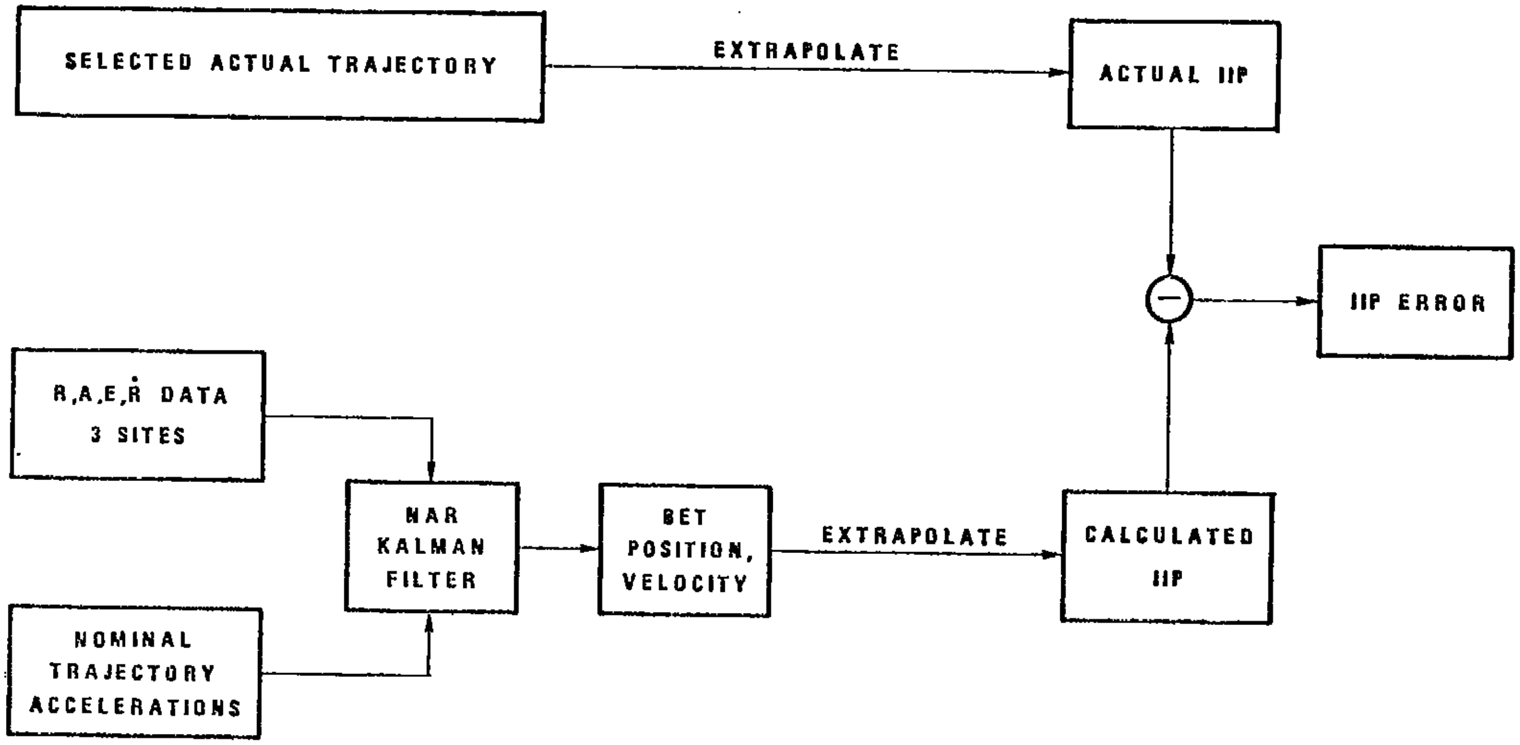
- GENERAL EXPLANATION OF PROBLEM
    - MISSILE/SENSOR GEOMETRY
    - $\dot{R}$ MEASUREMENTS
    - IIP POSITIONS, IIP ERRORS
- DESCRIPTION OF SOLUTION TECHNIQUES
    - COMPUTER SIMULATION (ARMS)
    - TWO KALMAN FILTERS (ARMS)
- SPECIFICATION OF CONDITIONS SIMULATED
- DISPLAYS OF IIP ERRORS
    - $\dot{R}$ DATA PRESENT
    - $\dot{R}$ DATA ABSENT
- SUMMARY REMARKS

GEOMETRY OF $\dot{R}$, IIP POSITION, IIP ERROR

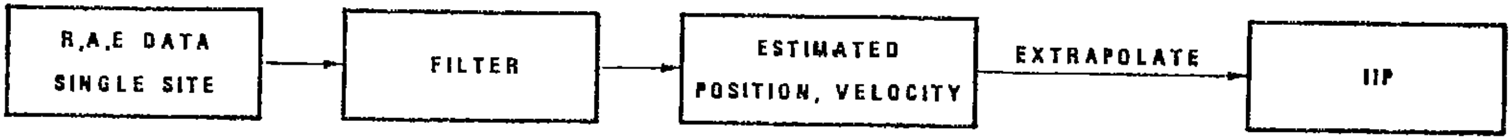


FLOW OF ARMS SIMULATOR

WITH NOMINAL ACCELERATION / RADAR FILTER (NAR)

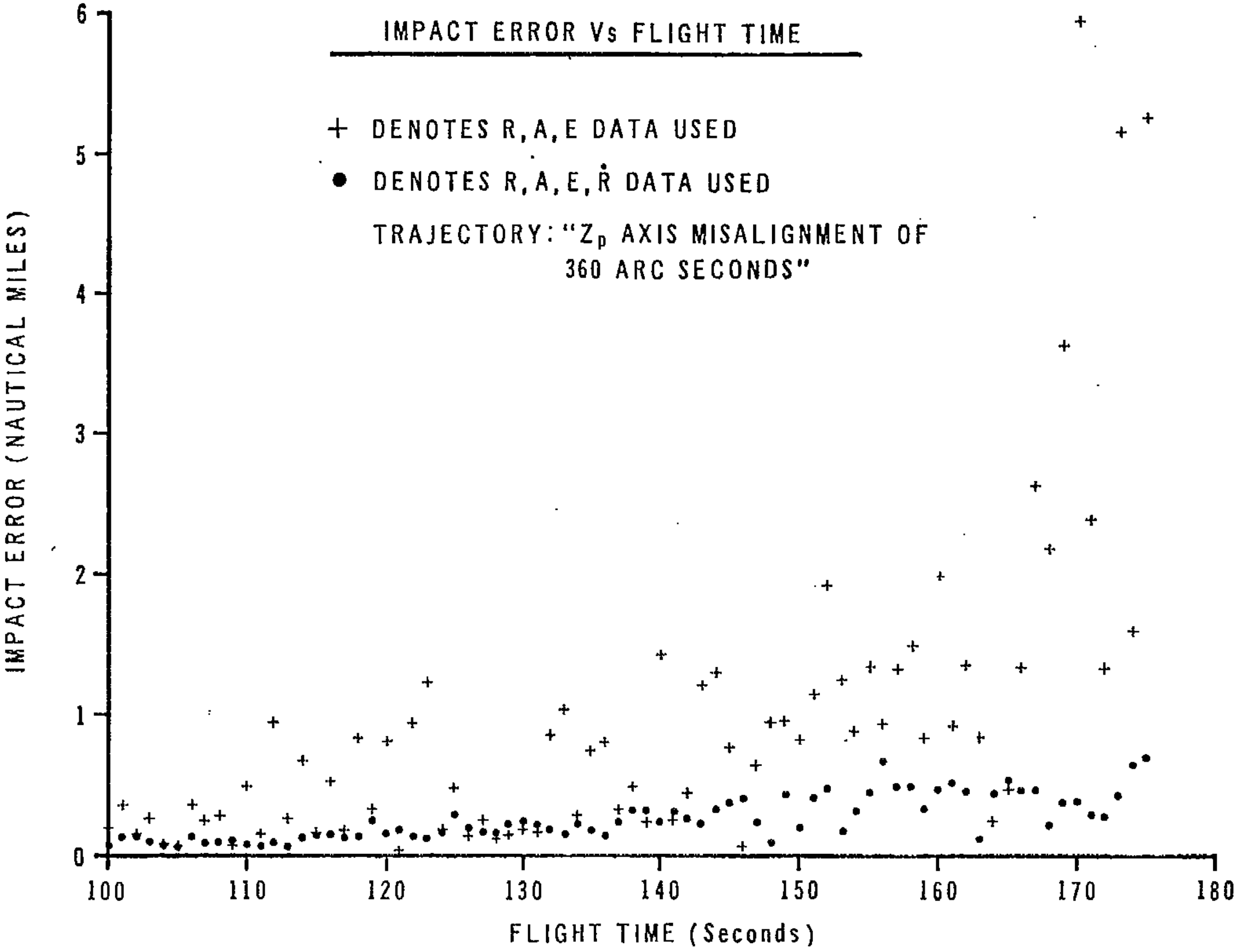


FLOW OF CURRENT OPERATIONAL SOFTWARE

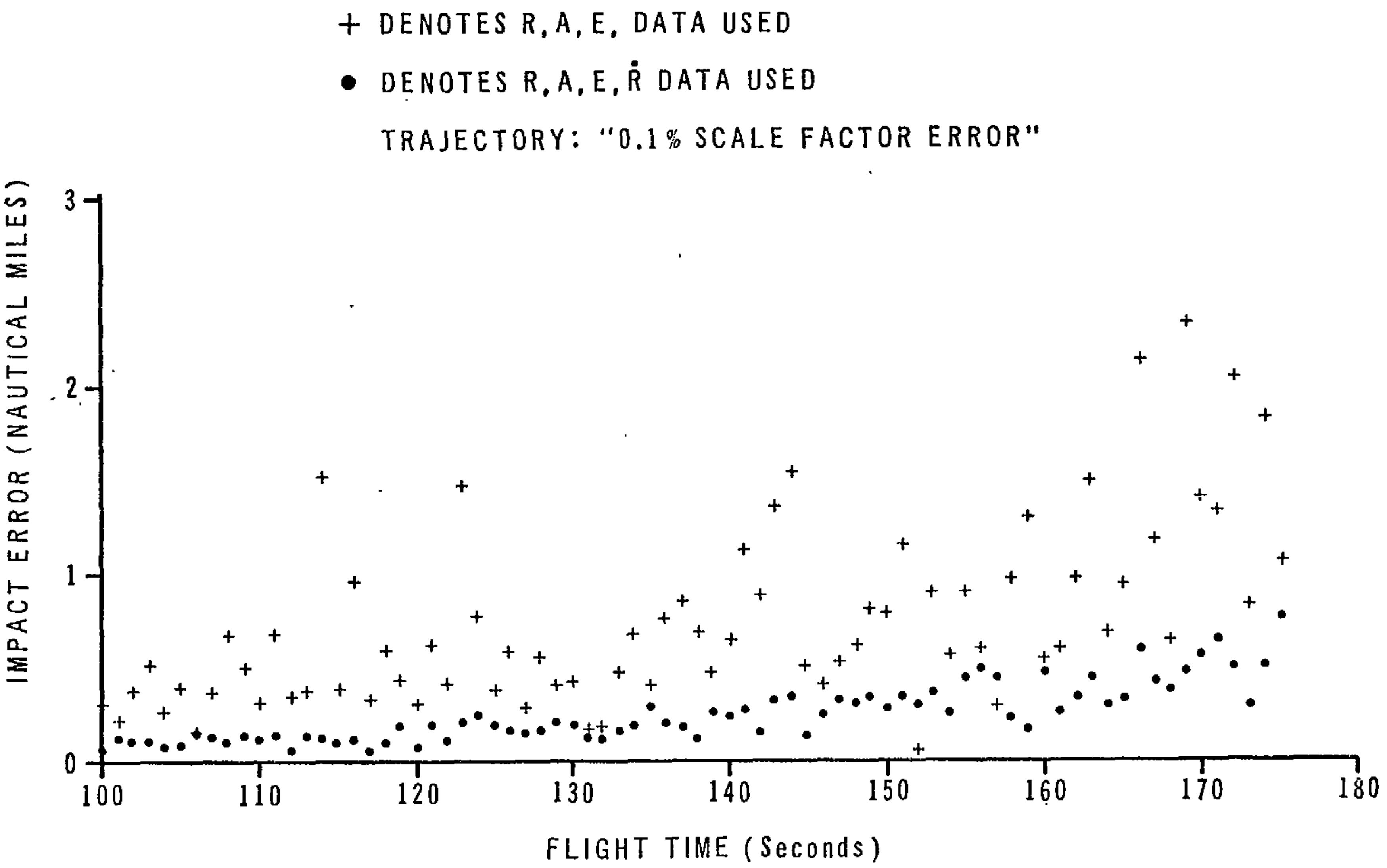


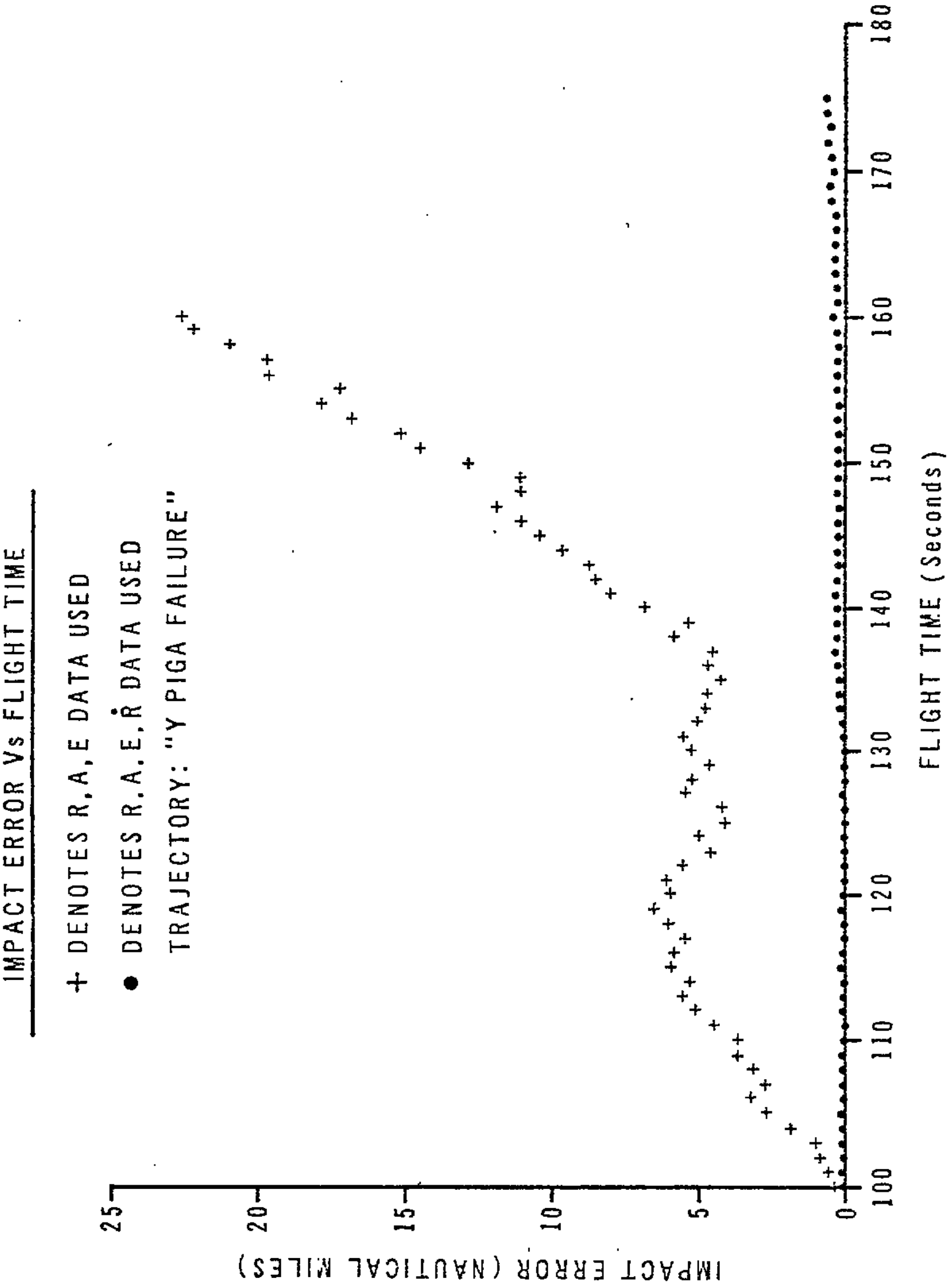
INFORMATION PERTINENT TO RESULTS

- 1 "NOMINAL" AND 3 "ACTUAL" MINUTEMAN III TRAJECTORIES WERE SIMULATED
    - PLATFORM MISALIGNMENT ABOUT Z_p AXIS OF 360 ARC SECONDS
    - 0.1 % SCALE FACTOR ERROR IN Y PIGA (PENDULOUS INTEGRATING GYROSCOPIC ACCELEROMETER) AXIS
    - Y PIGA FAILURE AFTER 100 SECONDS OF FLIGHT
- SECOND AND THIRD STAGE TRAJECTORY SEGMENT WAS USED
- DATA TYPICAL OF CALIBRATED RADARS WITH TYPICAL RANDOM ERRORS WERE SIMULATED
- $R, A, E, \dot{R}$ DATA FROM POINT MUGU (FPS-16), SAN NICOLAS ISLAND (FPS-16), AND POINT PILLAR (FPQ-6) WERE PROCESSED BY THE NAR FILTER
- COMPANION DATA SETS WITHOUT $\dot{R}$ WERE PROCESSED

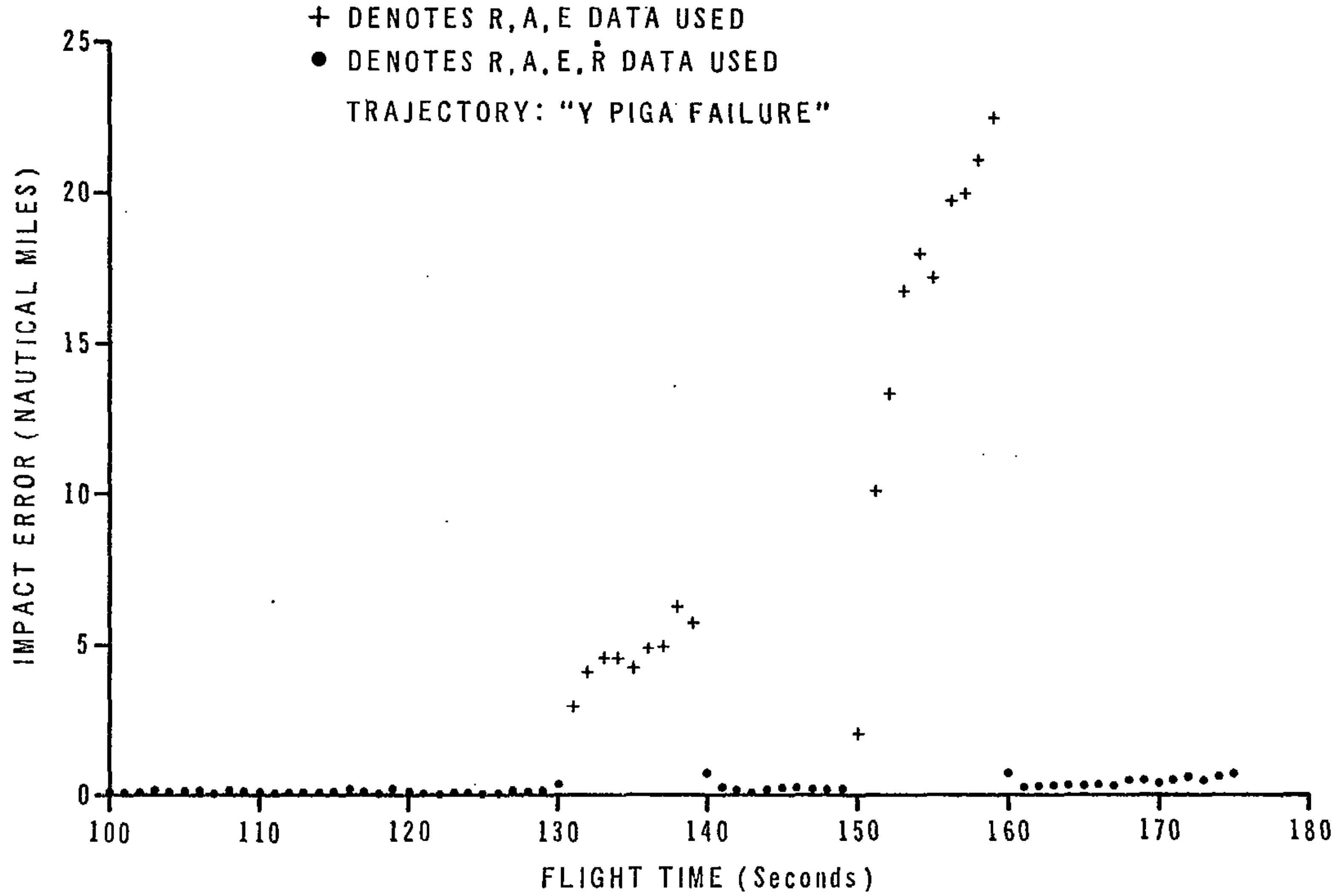

IMPACT ERROR Vs FLIGHT TIME
+ DENOTES R, A, E DATA USED
● DENOTES R, A, E, $\dot{R}$ DATA USED
TRAJECTORY: "Z_p AXIS MISALIGNMENT OF 360 ARC SECONDS"
IMPACT ERROR (NAUTICAL MILES)
0
1
2
3
4
5
6
FLIGHT TIME (Seconds)
100
110
120
130
140
150
160
170
180

IMPACT ERROR Vs FLIGHT TIME




IMPACT ERROR Vs FLIGHT TIME
+ DENOTES R, A, E DATA USED
● DENOTES R, A, E, Ṙ DATA USED
TRAJECTORY: "Y PIGA FAILURE"
IMPACT ERROR (NAUTICAL MILES)
0
5
10
15
20
25
100
110
120
130
140
150
160
170
180
FLIGHT TIME (Seconds)

IMPACT ERROR Vs FLIGHT TIME



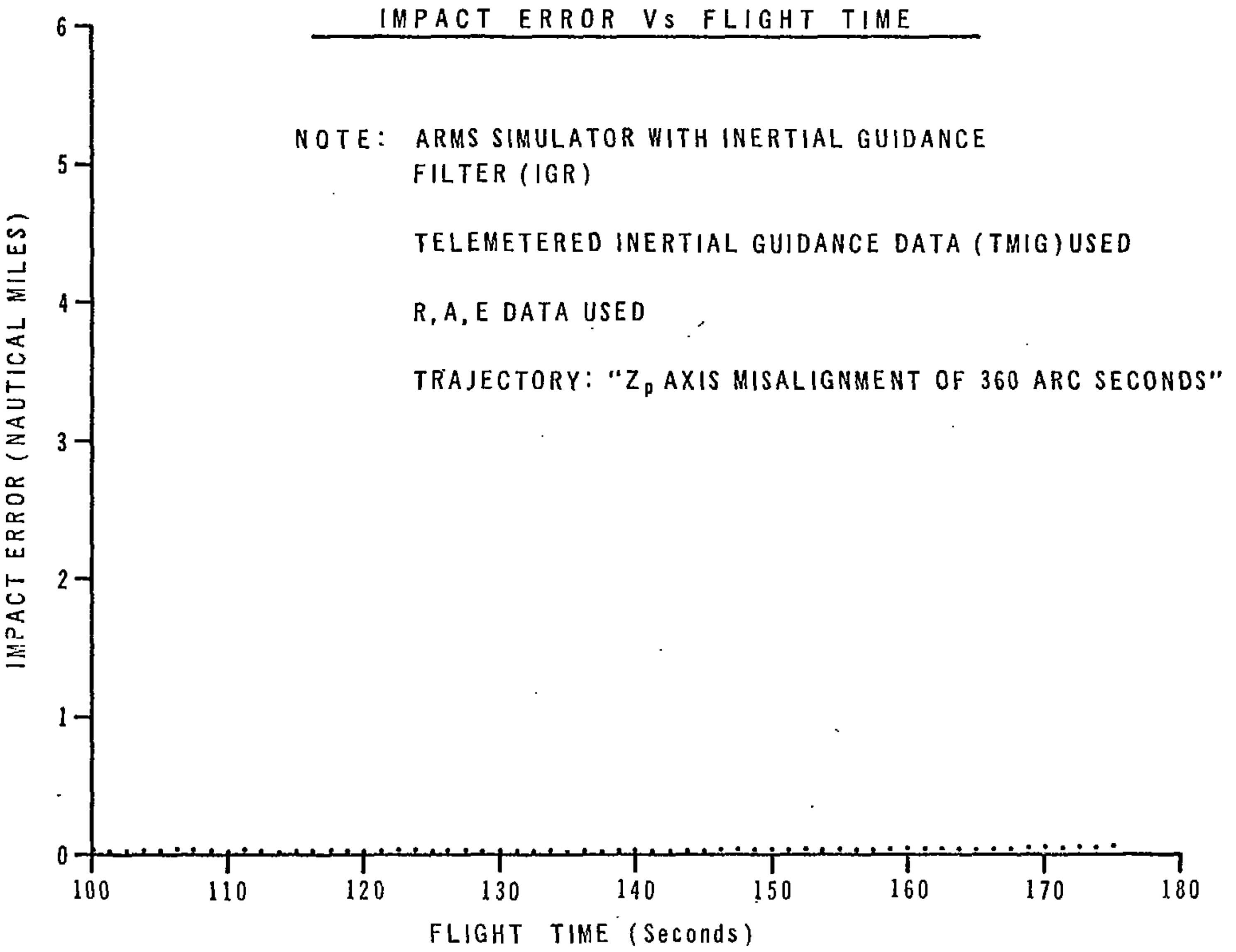
SEQUENTIAL TABULATION OF IIP ERRORS FROM NAR

TRAJECTORY: "Y PIGA FAILURE"

RELATIVE TO A GIVEN FLIGHT TIME, R, A, E, $\dot{R}$ DATA FROM 3 SITES WERE PROCESSED IN THE ORDER SHOWN BELOW.

IIP ERROR (NAUTICAL MILES)

FLIGHT TIME (SECONDS)	POINT MUGU	SAN NICOLAS ISLAND	POINT PILLAR
100	0.1	0.1	0.1
105	0.4	0.3	0.1
110	0.6	0.3	0.1
115	0.6	0.3	0.1
120	0.6	0.3	0.1
125	0.4	0.2	0.1
130	0.5	0.4	0.1
135	1.0	1.0	0.3
140	1.4	1.6	0.4
145	1.7	1.5	0.3
150	2.1	1.9	0.3
155	2.6	2.1	0.3
160	3.3	2.6	0.4
165	4.2	3.3	0.4
170	5.0	4.0	0.4
175	6.2	4.7	0.6



IMPACT ERROR Vs FLIGHT TIME

NOTE: ARMS SIMULATOR WITH INERTIAL GUIDANCE FILTER (IGR)

TELEMETERED INERTIAL GUIDANCE DATA (TMIG) USED

R, A, E DATA USED

TRAJECTORY: "Z_p AXIS MISALIGNMENT OF 360 ARC SECONDS"

SUMMARY REMARKS

- $\dot{R}$ MEASUREMENTS CAN PROVIDE
  - SMALLER IIP ERRORS AND
  - LESS NOISY IIP ERRORS
- SUBSTANTIAL IMPROVEMENTS OF IIP ACCURACY CAN BE OBTAINED WHEN
  - POINTING AXES OF AT LEAST 3 RADAR SITES ARE NOT IN THE SAME PLANE AND
  - BENEFITS OF $\dot{R}$ MEASUREMENTS ARE EXPLOITED BY THE SOFTWARE USED AND
  - GOOD MISSILE VELOCITY OR ACCELERATION COMPONENTS ARE NOT AVAILABLE FROM OTHER SOURCES

APPENDIX F

ANALYTICAL TECHNIQUES AND RESULTS OF COHERENT TRACKING OF THE THOR-DELTA AND MINUTEMAN III

By

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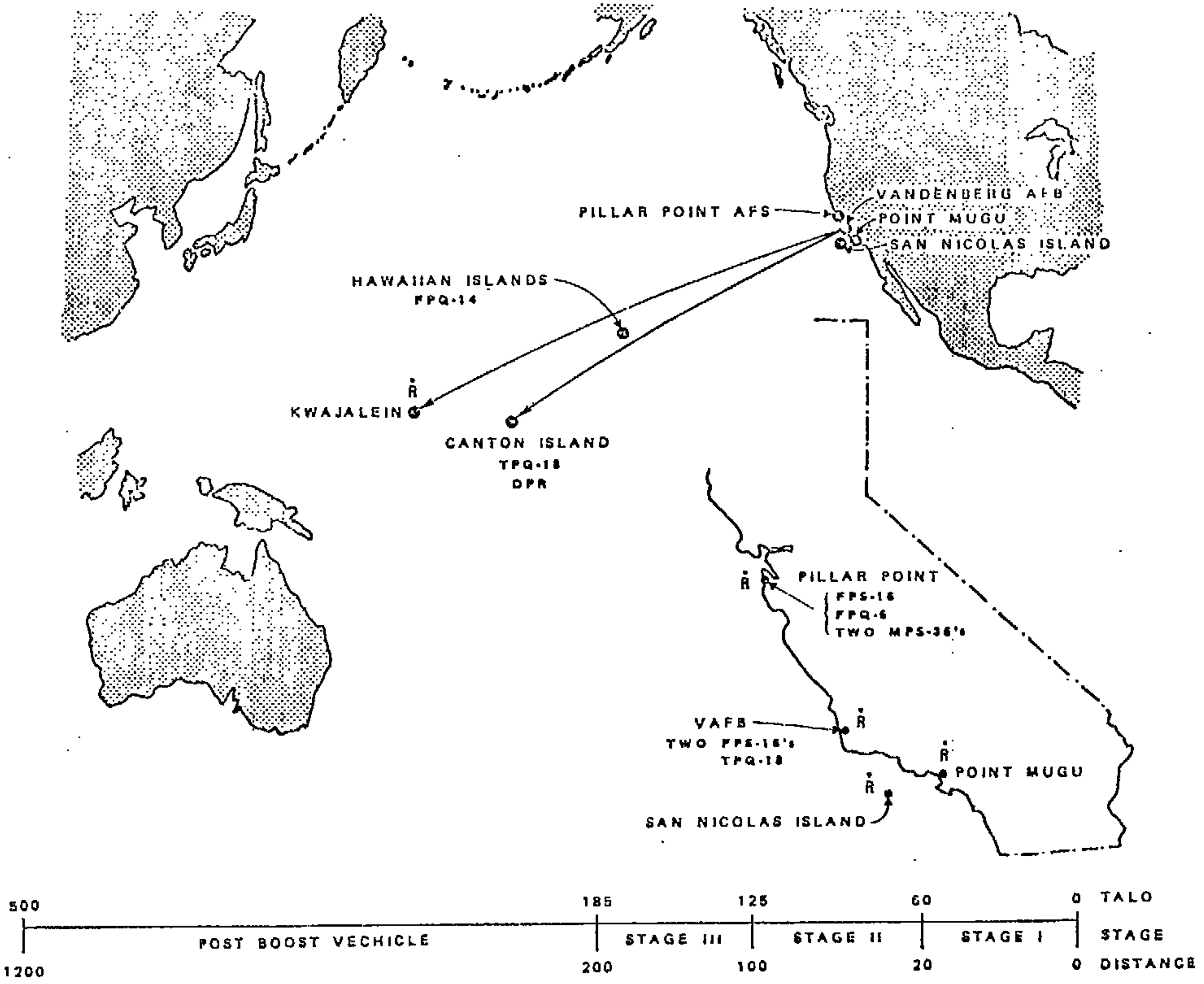
Vandenberg AFB, California 93437


PILLAR POINT AFS
VANDENBERG AFB
POINT MUGU
SAN NICOLAS ISLAND
HAWAIIAN ISLANDS
FPQ-14
R
KWAJALEIN
CANTON ISLAND
TPQ-18
DPR
R
PILLAR POINT
FPS-16
FPQ-6
TWO MPS-36's
VAFB
TWO FPS-16's
TPQ-18
R
R
POINT MUGU
R
SAN NICOLAS ISLAND
500
185
125
60
0
TALO
POST BOOST VECHICLE
STAGE III
STAGE II
STAGE I
STAGE
1200
200
100
20
0
DISTANCE

ANALYTICAL TECHNIQUES USED FOR POSITION DATA

- RANDOM ERROR AND SERVO ERROR EVALUATION
- RADAR COVERAGE (R, A, E DATA)
- SYSTEMATIC ERROR EVALUATION
    1. BEST ESTIMATE OF TRAJECTORY (BET) FORMED FROM RADAR DATA
    2. SYSTEMATIC ERRORS ESTIMATED FOR RADAR MEASUREMENTS USING BET STANDARD
    3. RESIDUAL ERRORS FORMED BY TRANSFORMING BET TO EACH RADAR SITE AND DIFFERENCING WITH RADAR R, A, E DATA CORRECTED FOR ESTIMATED ERRORS
- POST LAUNCH INSTRUMENTATION ACCURACY REPORT (PLIAR)

ANALYTICAL TECHNIQUES USED FOR DOPPLER $\dot{R}$ DATA

- RANDOM ERROR EVALUATION
- DOPPLER $\dot{R}$ DATA COVERAGE
- DOPPLER $\dot{R}$ DATA QUALITY MONITORING
- SYSTEMATIC ERROR EVALUATION

  1. BEST ESTIMATE OF TARGET VELOCITY (WEIGHTED LEAST SQUARES SOLUTION) FORMED BY COMBINING:
     - DIFFERENTIATED RADAR POSITION DATA WITH DOPPLER $\dot{R}$ DATA
     - INERTIAL GUIDANCE $\dot{X}$, $\dot{Y}$, $\dot{Z}$ DATA WITH DOPPLER $\dot{R}$ DATA
  2. INERTIAL GUIDANCE DATA
  3. INERTIAL GUIDANCE BET

POTENTIAL STANDARDS FOR SYSTEMATIC ERROR EVALUATION

- BEST ESTIMATE OF TARGET VELOCITY FORMED BY COMBINING DOPPLER $\dot{R}$ MEASUREMENTS FROM FOUR RADARS (REDUNDANT SOLUTION).

- BEST ESTIMATE OF TARGET POSITION AND VELOCITY FORMED USING RADAR POSITION (R,A,E) DATA AND:

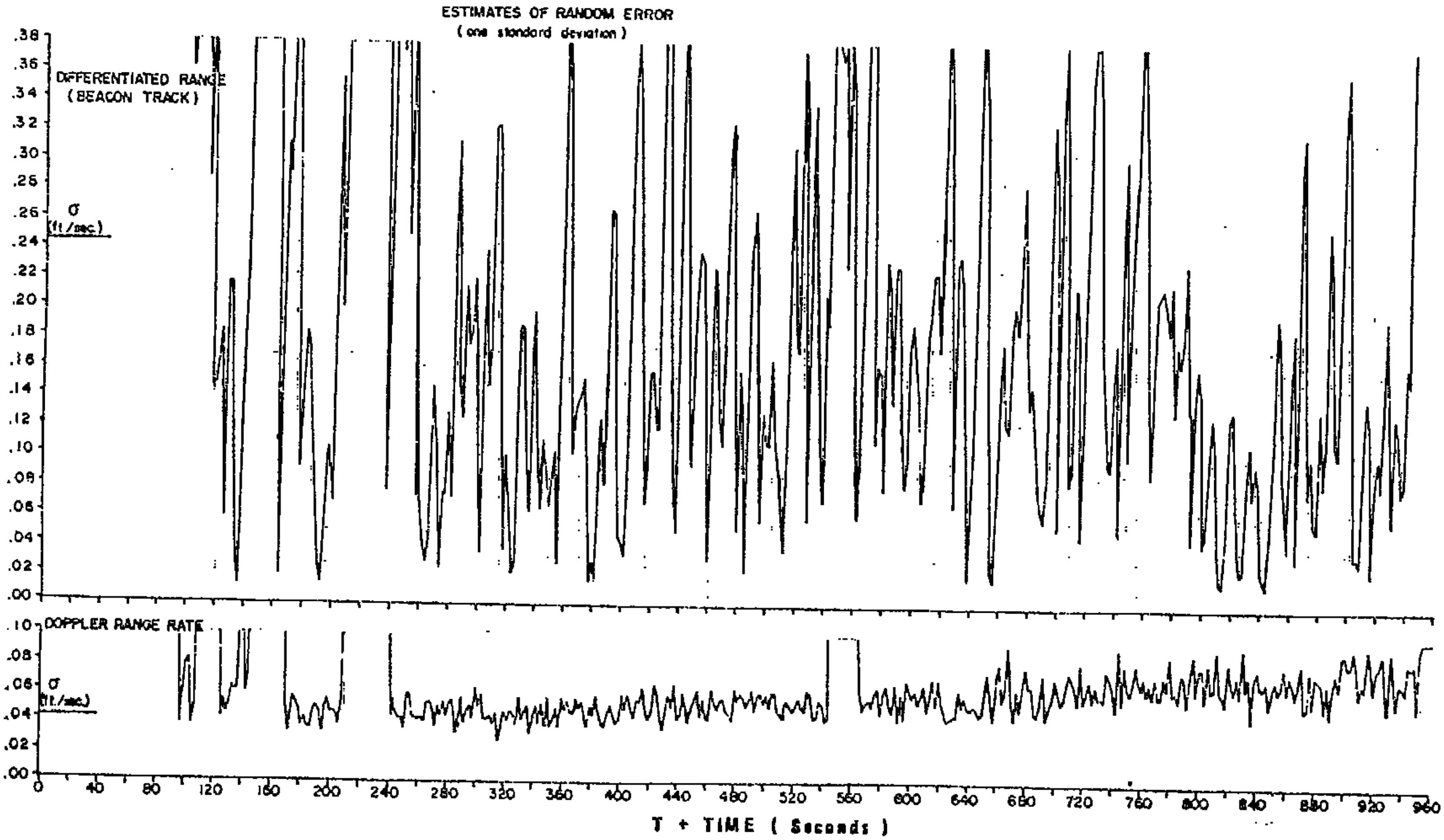
    1. EQUATIONS OF MOTION (COHERENT BEACON LOCATED IN OBJECT IN FREEFALL).
    2. POINT TO POINT CONSTRAINTS DURING POWERED FLIGHT.

(CURRENT SOFTWARE DOES NOT PERMIT POINT TO POINT CONSTRAINTS IN DETERMINING TRAJECTORY NOT IN FREEFALL. . . . . . .COHO BEACON HAS ALWAYS BEEN LOCATED IN A BOOSTER VEHICLE)

OPERATION NUMBER	LAUNCH DATE	TYPE OF LAUNCH	COMPARISON STANDARD	REPORT TITLE
4834	3/31/71	THOR – DELTA	WEIGHTED LEAST SQUARES SOLUTION COMBINING R, A, E AND DIFFERENTIATED R, A, E FROM TPQ-18, FPQ-6, Pt. MUGU $^{\#}$4, AND SNI $^{\#}$3, WITH DOPPLER $\dot{R}$ FROM TPQ-18, FPQ-6, AND Pt. MUGU $^{\#}$4.	C-BAND DOPPLER RANGE RATE ACCURACY ANALYSIS
3782	6/11/71	MM III	WEIGHTED LEAST SQUARES SOLUTION COMBINING RADAR POSITION DATA (R, A, E), INERTIAL GUIDANCE $\dot{X}$, $\dot{Y}$, $\dot{Z}$ DATA, AND DOPPLER $\dot{R}$ DATA FROM TPQ-18, FPQ-6, AND Pt. MUGU $^{\#}$4.	PLIAR, OPERATION 3782
3782	6/11/71	MM III	INERTIAL GUIDANCE DATA	C-BAND DOPPLER RANGE RATE DATA EVALUATION, OPERATIONS 3782, 6448, and 8482
6448	10/20/71	MM III	INERTIAL GUIDANCE DATA AND IG BET	
8482	12/15/71	MM III	INERTIAL GUIDANCE DATA	

ADDITIONAL MINUTEMAN III OPERATIONS USING INERTIAL GUIDANCE DATA AS A STANDARD

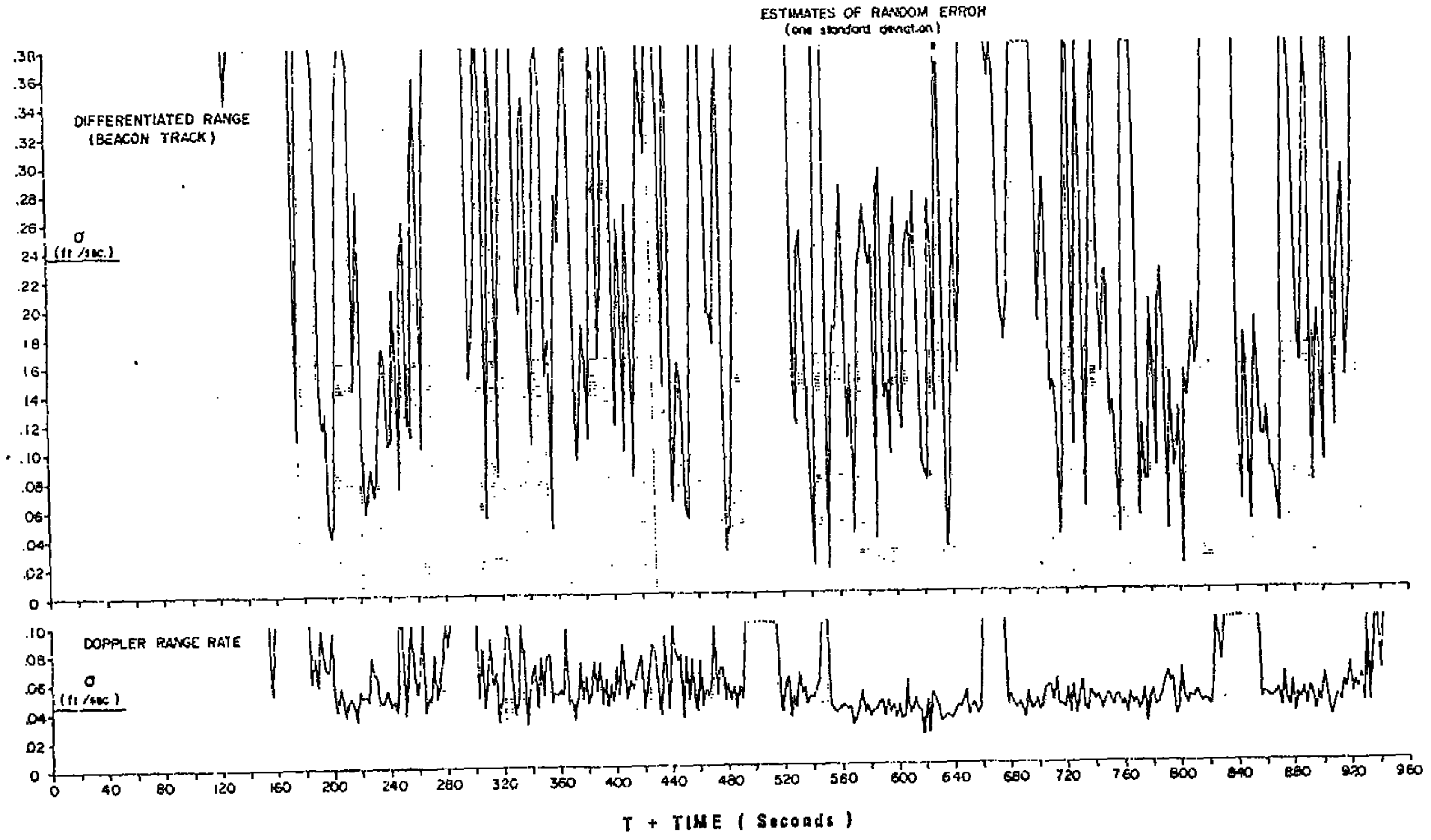
5477	5/31/72
1560	6/6/72
3519	6/18/72
7243	8/2/72
5179	1/30/73
3546	4/26/73
5411	5/31/73
4109	8/23/73
3686	12/22/73



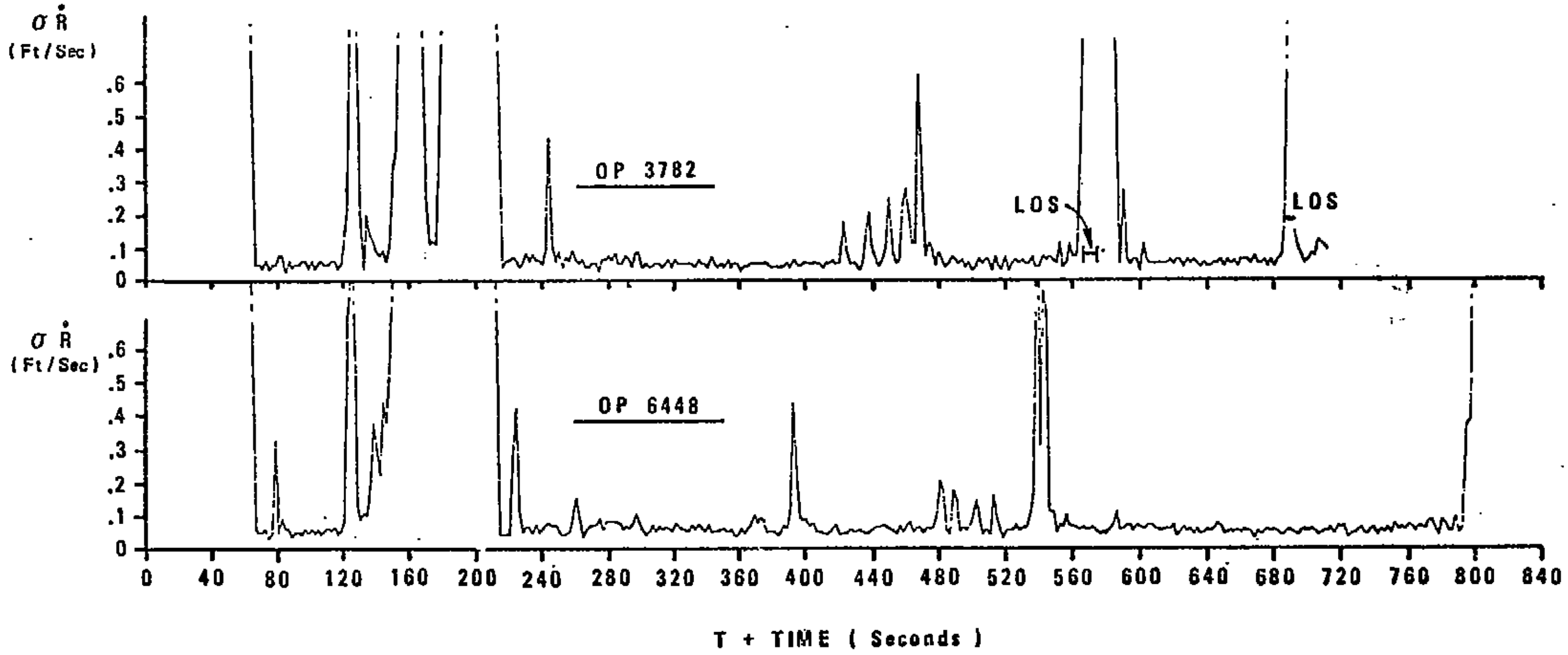
SVAFB TPQ-18 THOR-DELTA, OPERATION 4834

RANDOM ERROR EVALUATION

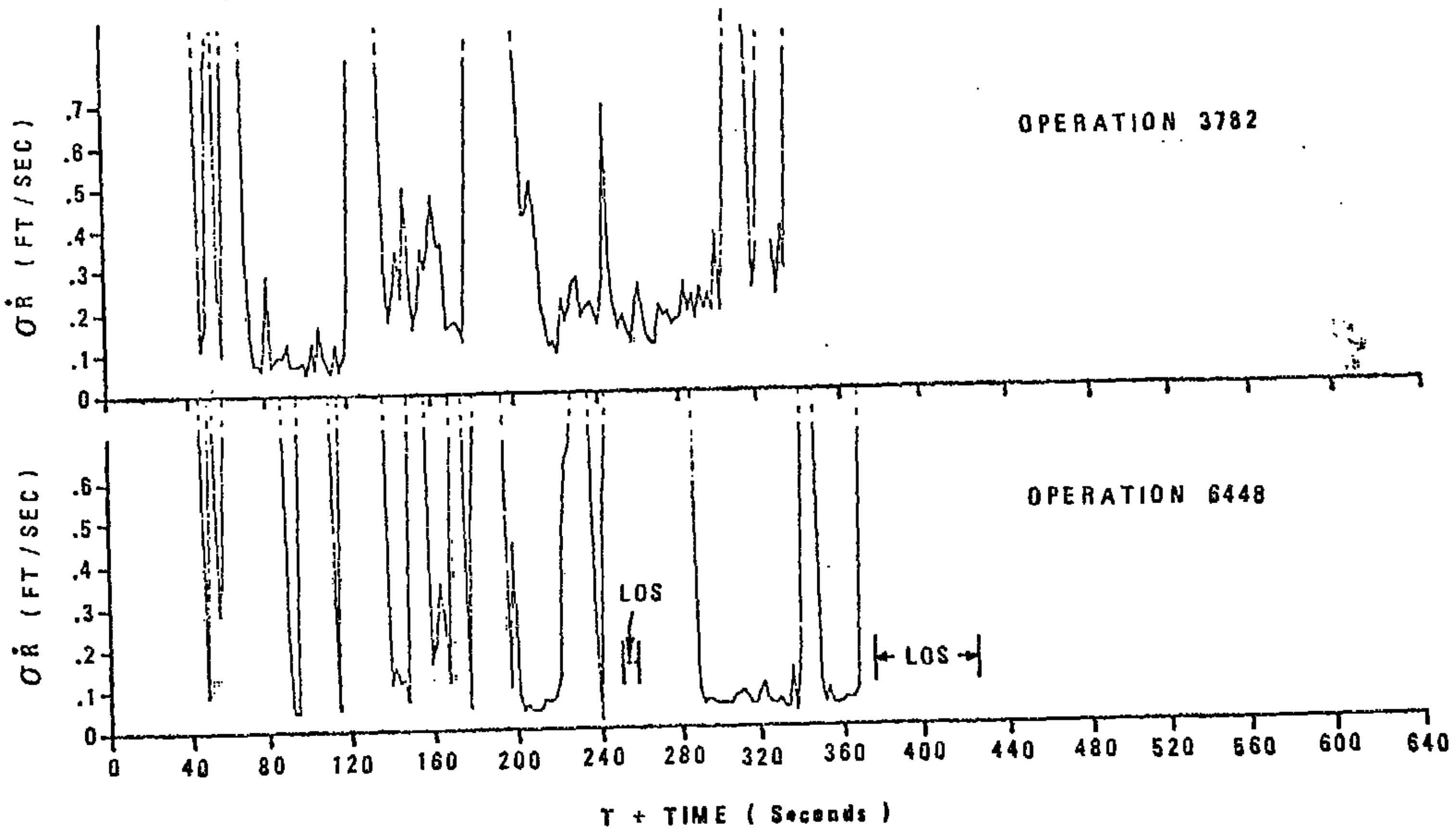
- MEASURE OF PRECISION OR REPEATABILITY
- POLYNOMIAL SMOOTHING (67 POINTS)
- ONE STANDARD DEVIATION (1 σ) VALUES FORMED AND PLOTTED EVERY TWO SECONDS



POINT PILLAR FPQ-6 THOR-DELTA, OPERATION 4834



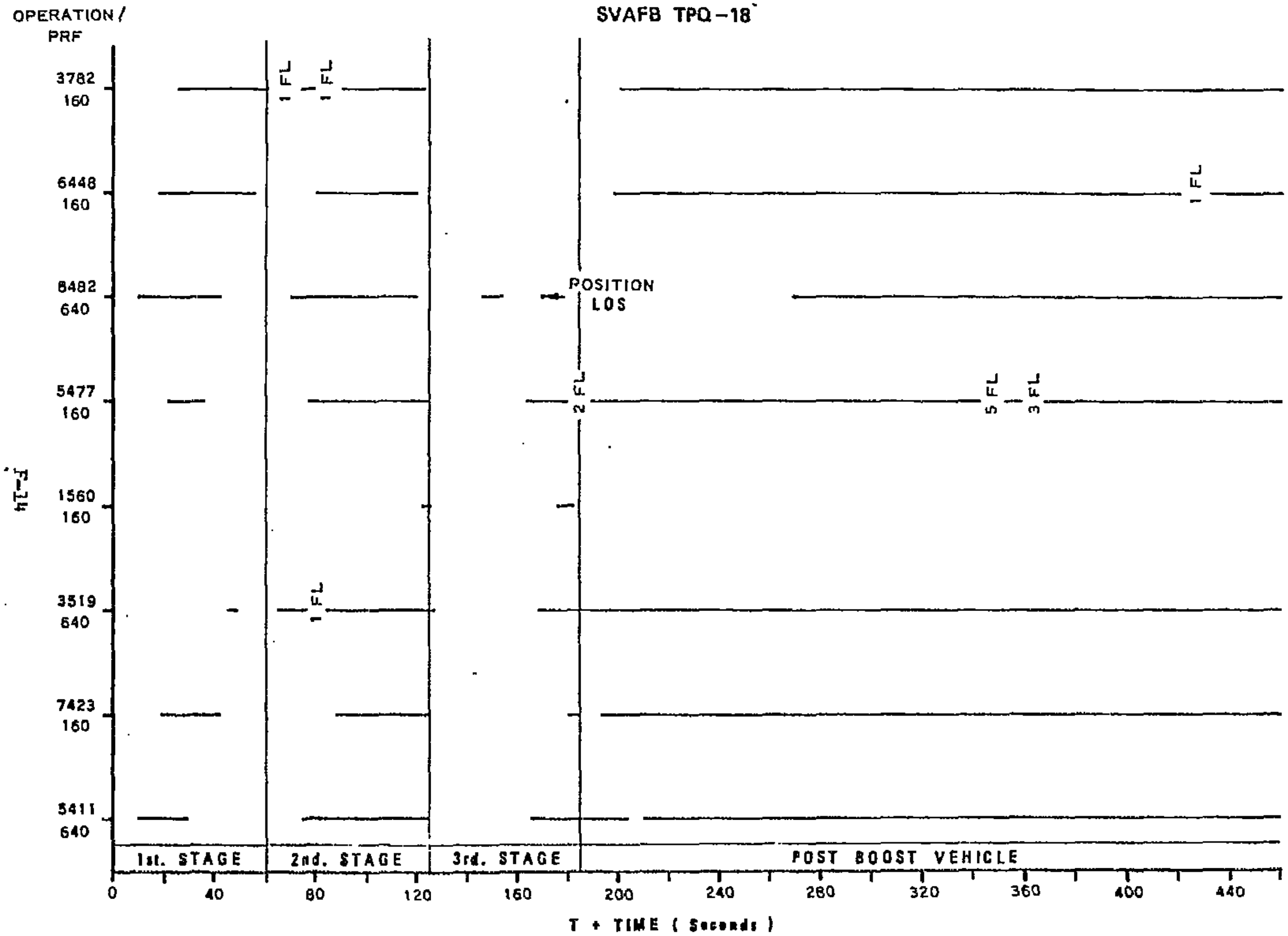
PILLAR POINT FPQ-6 RANDOM ERRORS, OPERATIONS 3782 and 6448



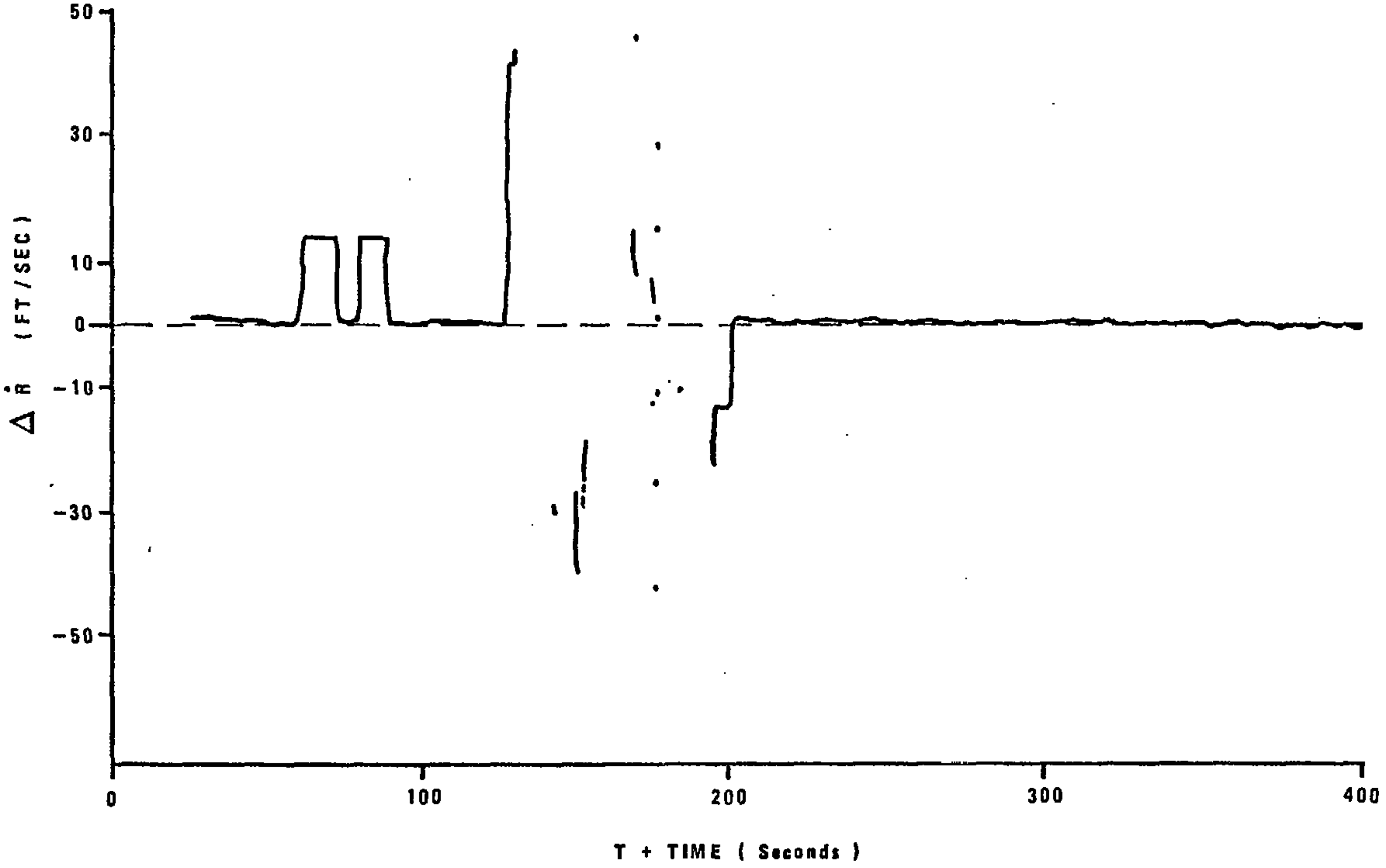
POINT MUGU FPS-16 #4 RANDOM ERRORS, OPERATIONS 3782 and 6448

DOPPLER DATA COVERAGE

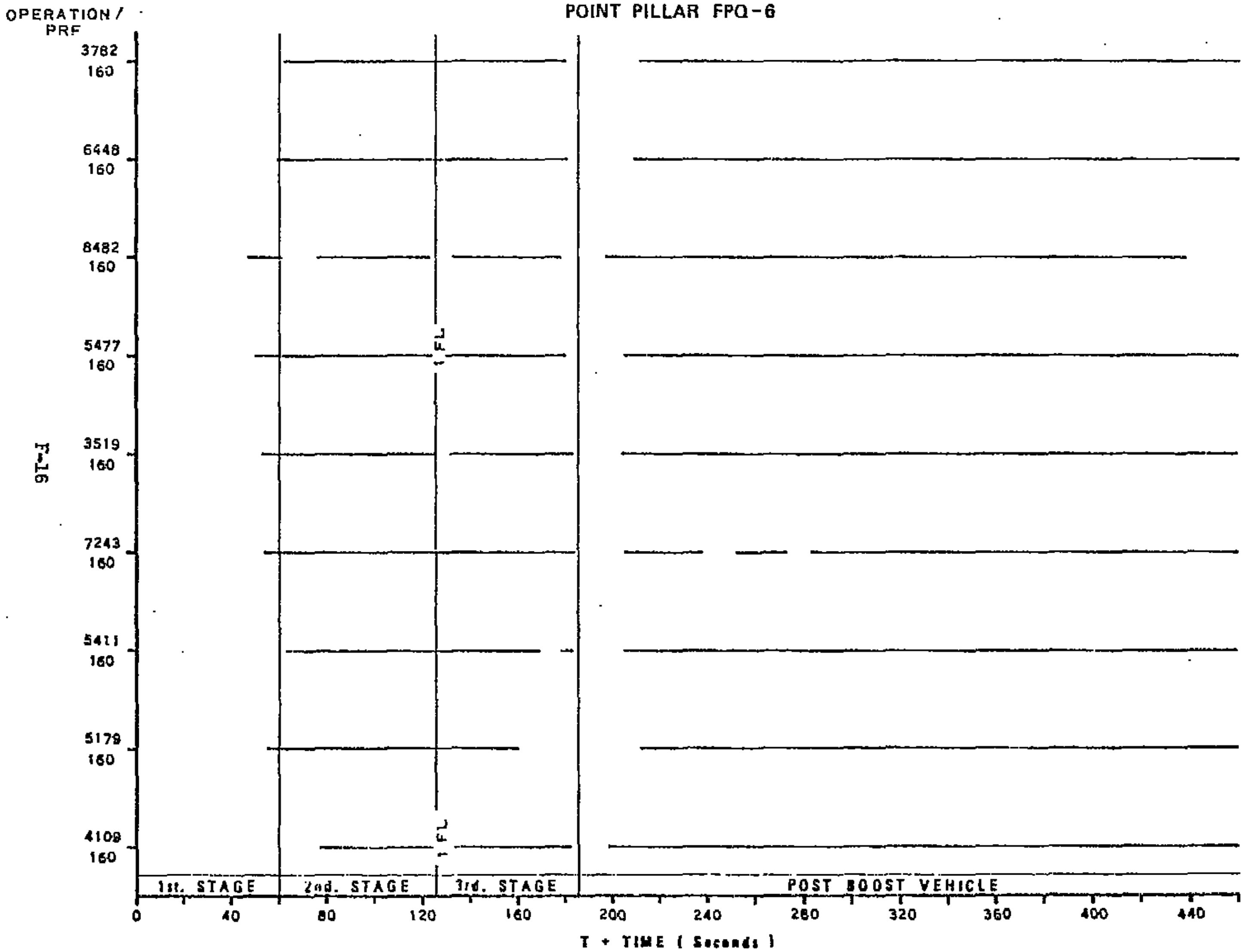
- DETERMINED BY EXAMINING INERTIAL GUIDANCE Versus DOPPLER $\dot{R}$ RESIDUALS
- DETERMINE WHETHER DOPPLER SIGNAL IS ON CENTER FINE LINE
- DETERMINE WHETHER DOPPLER SIGNAL IS ON i^{th} FINE LINE
- INERTIAL GUIDANCE DATA USUALLY ENDS BEFORE DOPPLER DATA



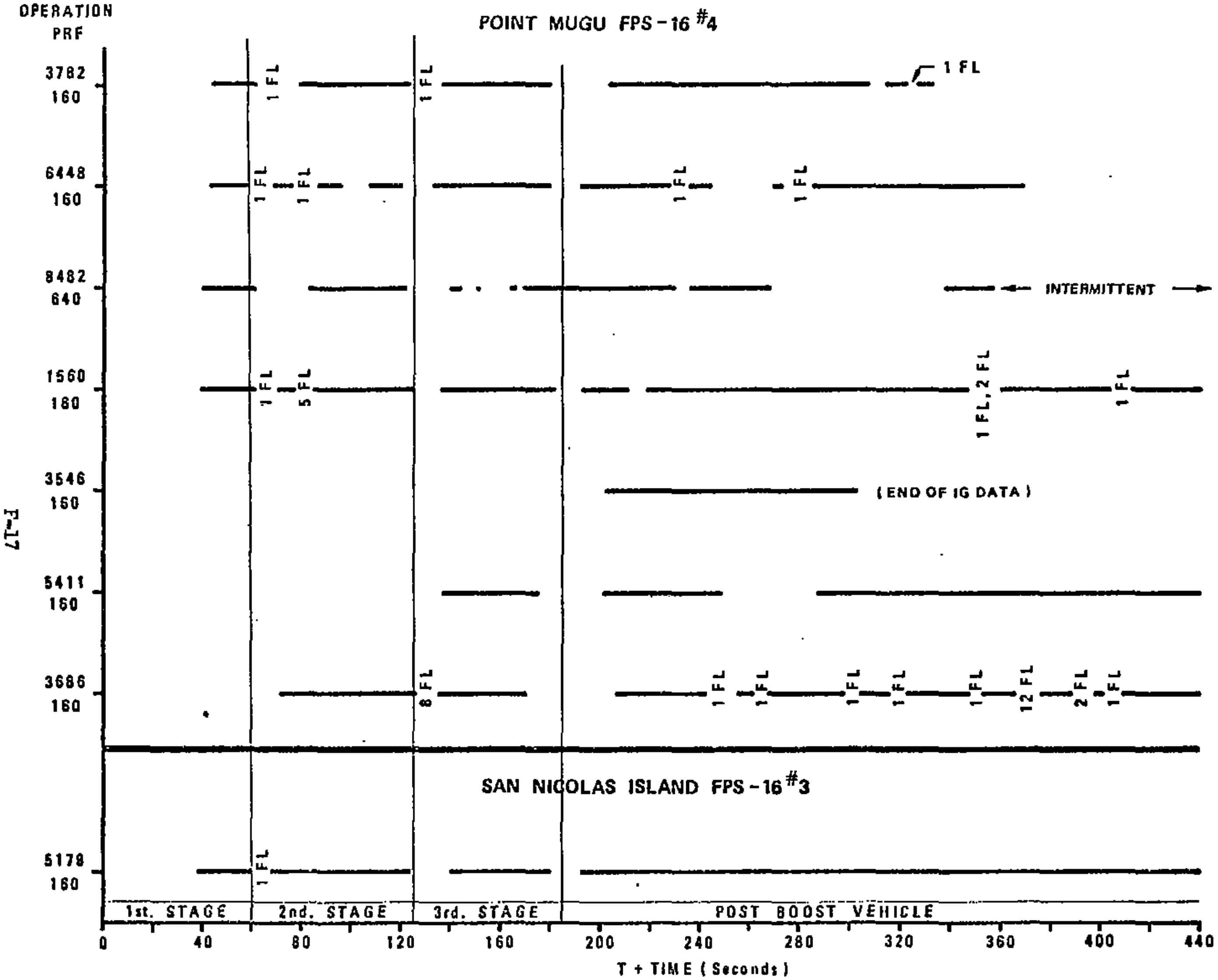
DOPPLER COVERAGE, MINUTEMAN III OPERATIONS



SVAFB TPQ-18 $\dot{R}$ Versus INERTIAL GUIDANCE, OPERATION 3782, 11 June 1971



DOPPLER COVERAGE, MINUTEMAN III OPERATIONS



DOPPLER COVERAGE, MINUTEMAN III OPERATIONS

SYSTEMATIC ERROR EVALUATION

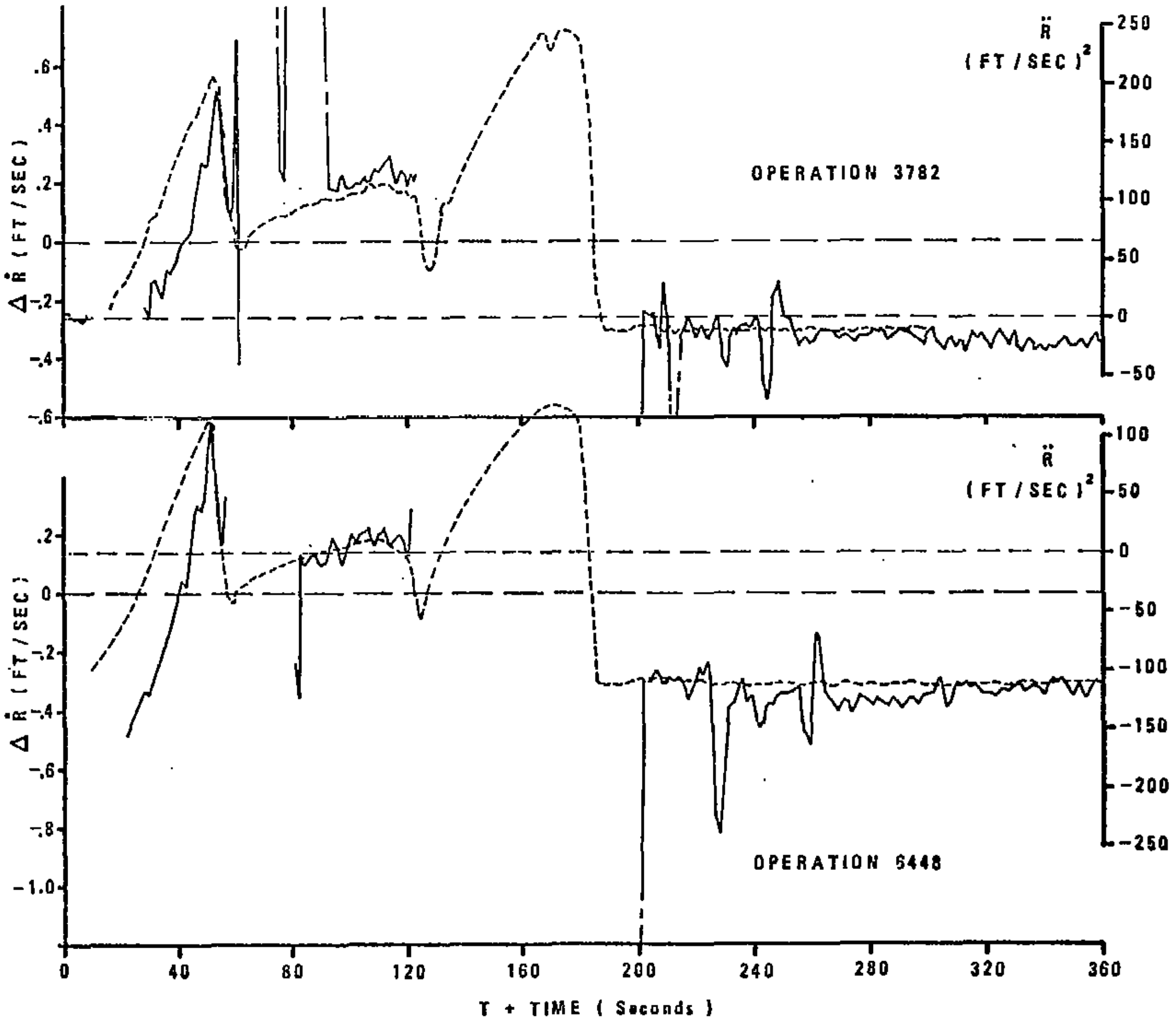
INERTIAL GUIDANCE RESIDUALS USED FOR SYSTEMATIC ERROR EVALUATION

- ADVANTAGES
  - MOST TIMELY STANDARD CURRENTLY AVAILABLE
  - USEFUL IN EVALUATING $\dot{R}$ REFRACTION ERRORS, $\dot{R}$ BIAS ERRORS

- DISADVANTAGE

  INADEQUATE FOR EVALUATION OF ACCELERATION DEPENDENT ERROR WHICH COULD BE CAUSED BY:

  - DOPPLER TIME TAG ERROR
  - DYNAMIC LAG
  - INERTIAL GUIDANCE AND RADAR TIMING ERROR
  - INERTIAL GUIDANCE DATA TIME DEPENDENT ERROR



$\ddot{R}$ AT SVAFB TPQ-18 and TPQ-18 $\dot{R}$ Versus INERTIAL GUIDANCE,
OPERATIONS 3782 and 6448

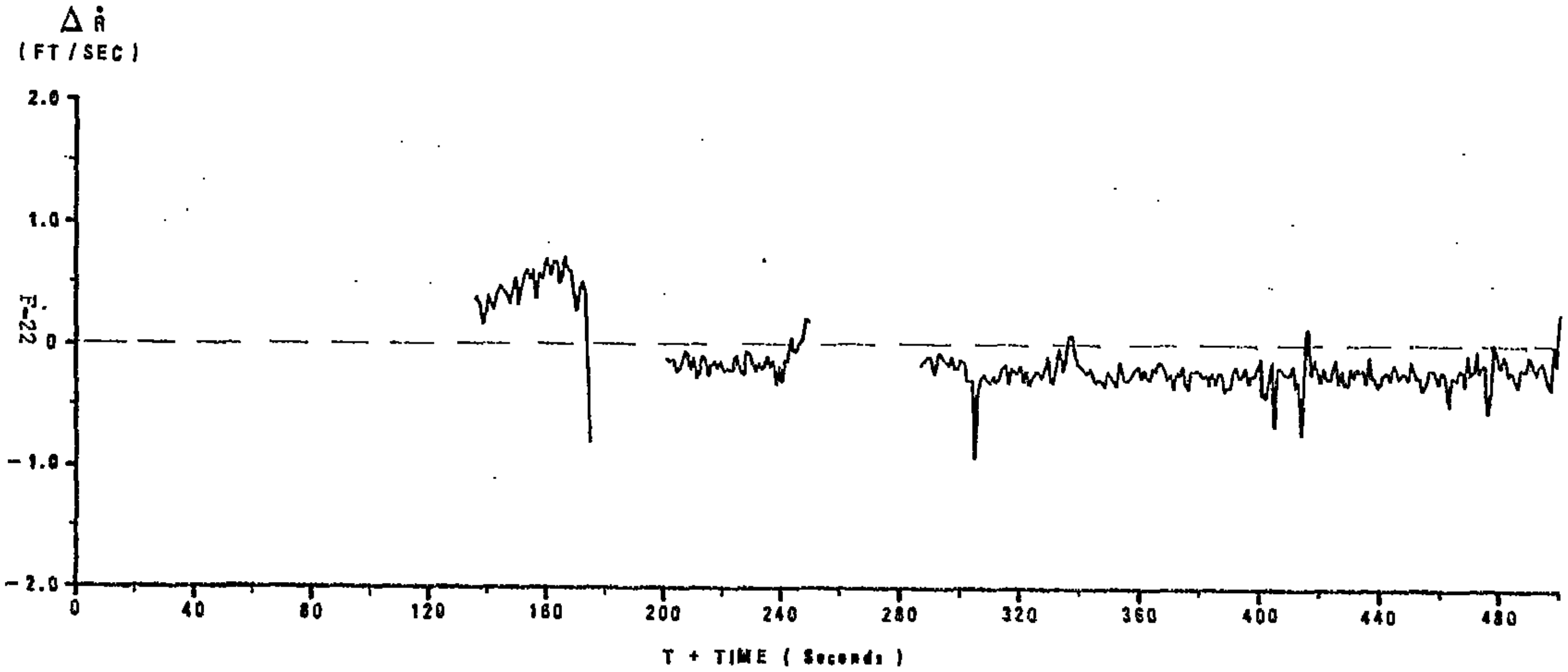
DOPPLER DATA EVALUATION STANDARD – IN SUMMARY

- TARGET VELOCITY BEST ESTIMATE FROM REDUNDANT $\dot{R}$ DATA – HAS HAD LIMITED SUCCESS DUE TO LARGE $\dot{R}$ SYSTEMATIC ERRORS, AND LIMITED NUMBER OF $\dot{R}$ SENSORS.
- INERTIAL GUIDANCE DATA SATISFACTORY FOR PERFORMANCE AND COVERAGE MONITORING.
- INERTIAL GUIDANCE DATA NOT ENTIRELY SATISFACTORY FOR SYSTEMATIC ERROR EVALUATION
- BETTER POSSIBILITY OF OBTAINING A BEST ESTIMATE OF TARGET VELOCITY FROM COMBINED DOPPLER $\dot{R}$ MEASUREMENTS (DEPENDING ON STATUS OF PMR DOPPLER RADARS).
- IMPROVED SOFTWARE TO APPLY TRAJECTORY CONSTRAINTS DURING POWERED FLIGHT WOULD ENABLE DOPPLER DATA EVALUATION USING POSITION OR POSITION AND VELOCITY DATA
- GEOS - C - COHERENT BEACON

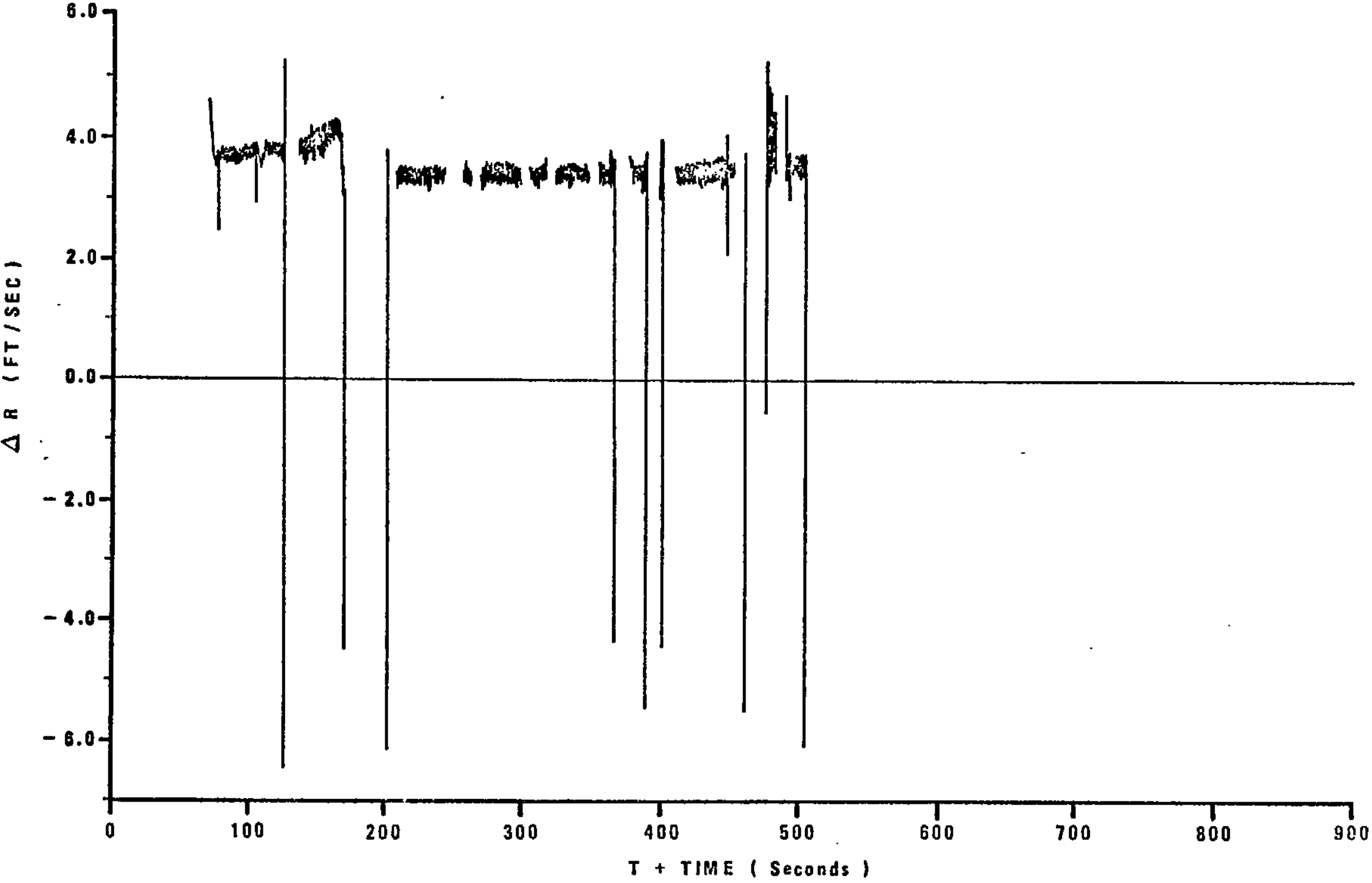
DOPPLER DATA — IN SUMMARY

BASED ON THE DATA ANALYZED

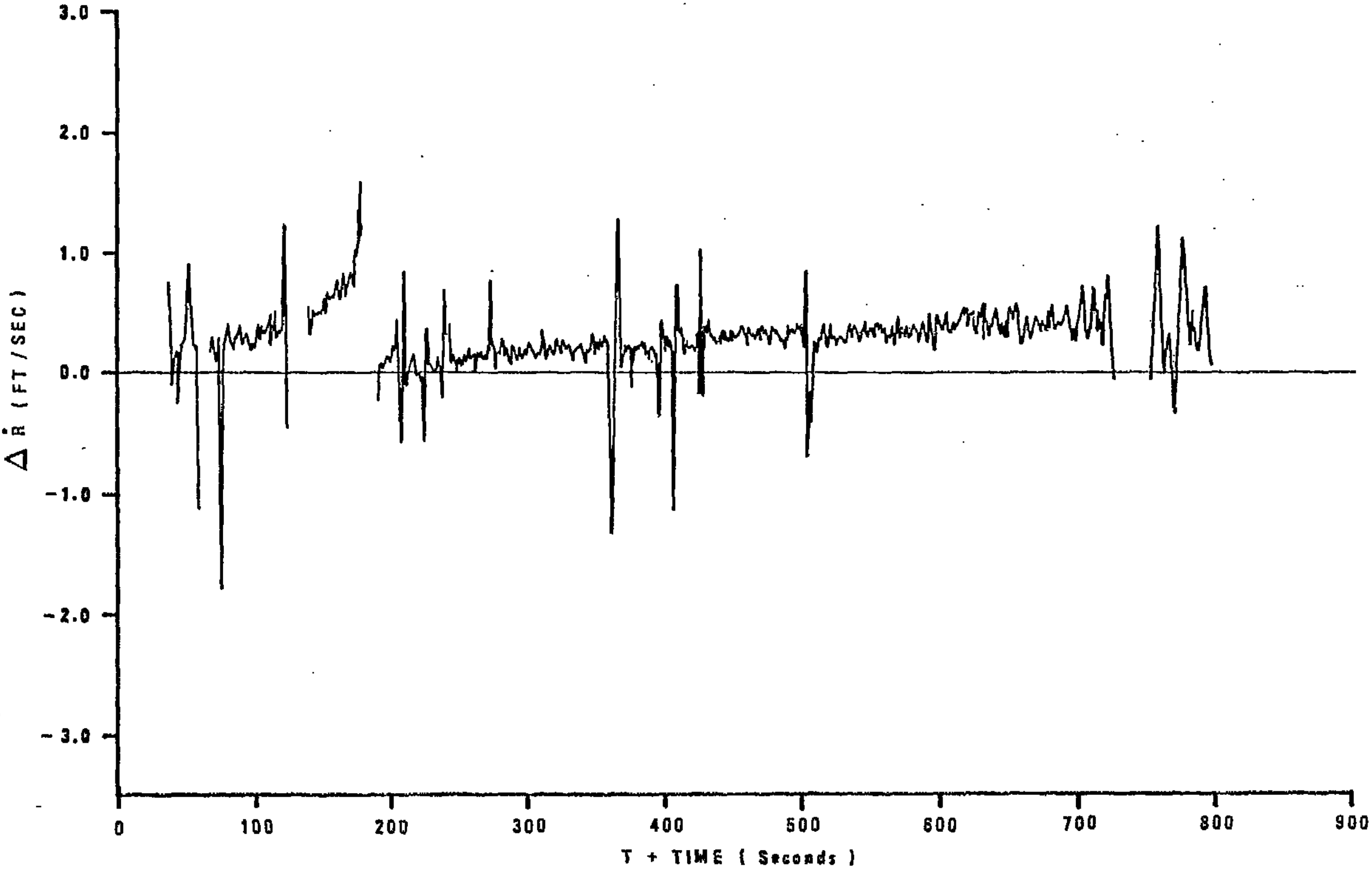
- $\dot{R}$ DATA SHOWS A PRECISION OF 0.1 fps
- $\dot{R}$ DATA IS PRESENTLY ACCURATE TO 1 fps (EXCLUDING BIAS)
- NEVER HAD USABLE DOPPLER DATA FROM ALL FOUR RADARS SIMULTANEOUSLY FOR A REDUNDANT SOLUTION
- NEVER HAD USABLE DOPPLER DATA FROM THE THREE RADARS NECESSARY FOR IMPACT PREDICTION



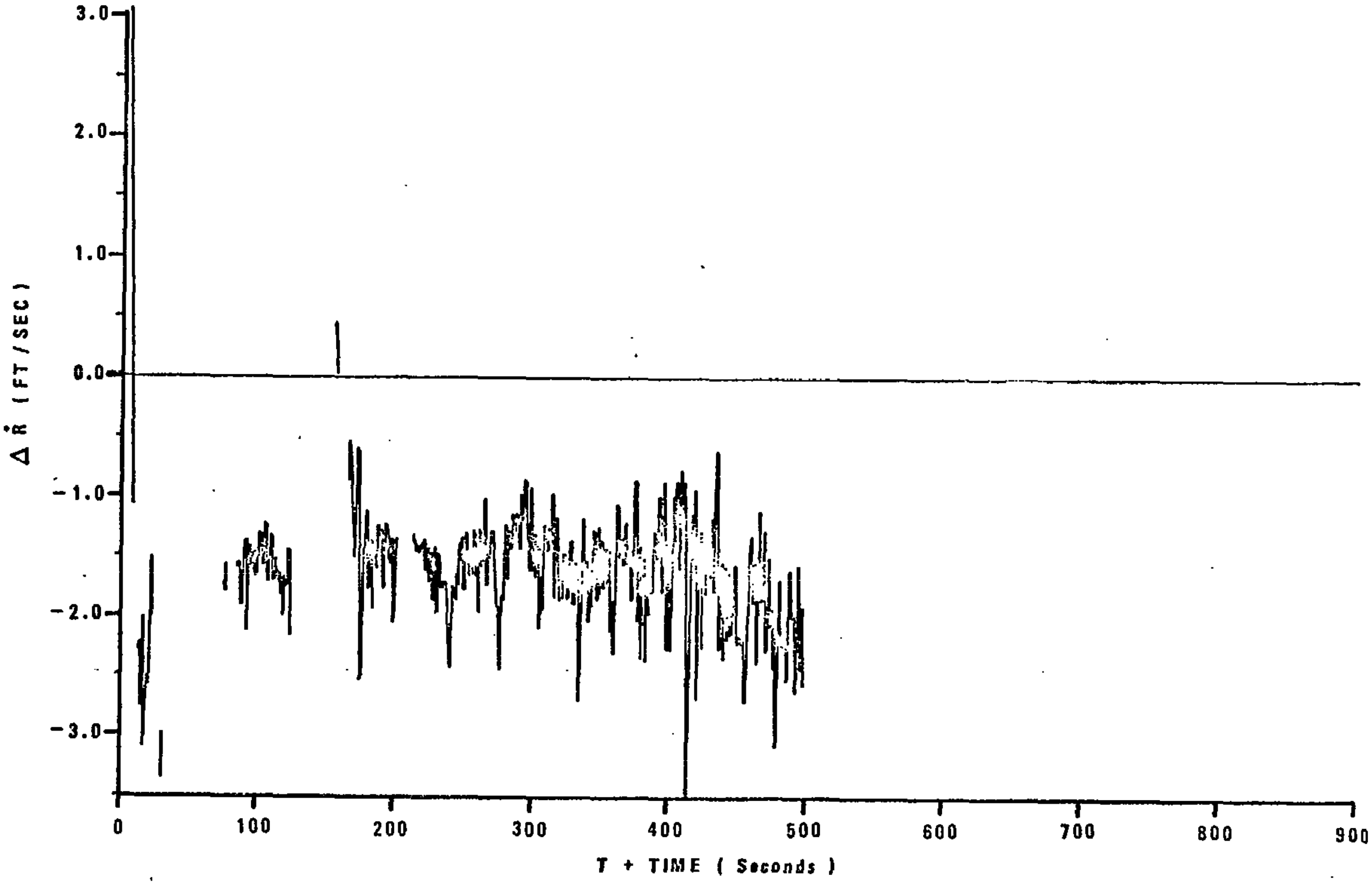
POINT MUGU FPS-16 $^{\#}4$ $\dot{R}$ Versus INERTIAL GUIDANCE, OPERATION 5411



POINT MUGU FPS-16 #4 $\dot{R}$ Versus INERTIAL GUIDANCE, OPERATION 3686



SAN NICOLAS ISLAND FPS-16 #3 $\dot{R}$ Versus INERTIAL GUIDANCE, OPERATION 5179



SVAFB TPQ-18 $\dot{R}$ Versus INERTIAL GUIDANCE, OPERATION 5411

DOPPLER DATA — IN SUMMARY

BASED ON THE DATA ANALYZED

- $\dot{R}$ DATA SHOWS A PRECISION OF 0.1 fps
- $\dot{R}$ DATA IS PRESENTLY ACCURATE TO 1 fps (EXCLUDING BIAS)
- NEVER HAD USABLE DOPPLER DATA FROM ALL FOUR RADARS SIMULTANEOUSLY FOR A REDUNDANT SOLUTION
- NEVER HAD USABLE DOPPLER DATA FROM THE THREE RADARS NECESSARY FOR IMPACT PREDICTION

APPENDIX G

COHERENT TRACKING OF MINUTEMAN III MEASUREMENT SYSTEM PROBLEMS AND EVALUATION

By

WILLIAM COLLINS, FEC

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Vandenberg AFB, California 93437

INSTALLATION OF PULSE DOPPLER EQUIPMENT AT WTR

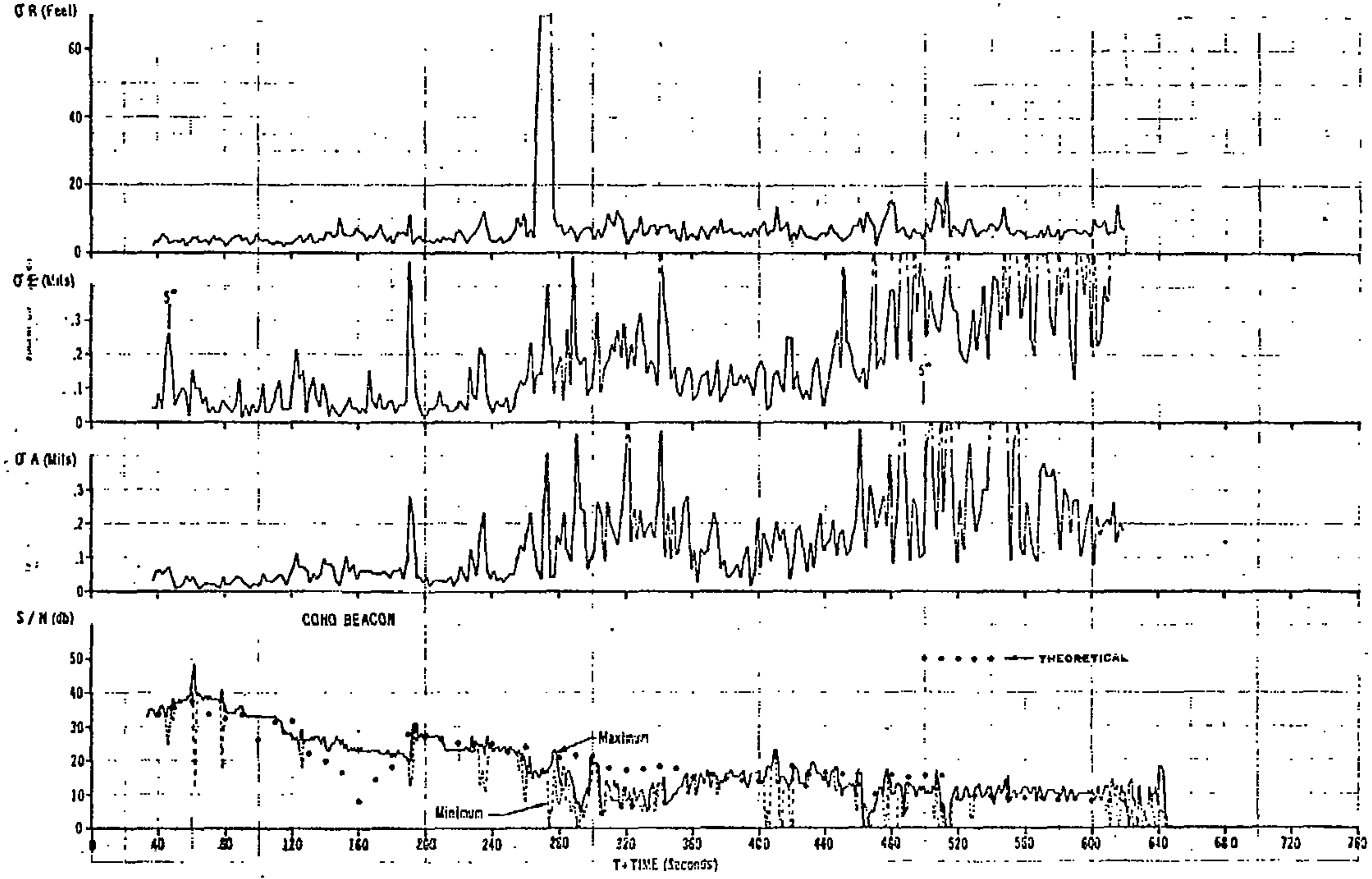
SVAFB	023003	TPQ-18	CSP INSTALLED	JUNE 1968
PILLAR POINT	213002	FPQ-6	CSP INSTALLED	JANUARY 1971
MOBILE	213003	MPS-36	CAT II COMPLETED	FEBRUARY 1972
MOBILE	213004	MPS-36	CAT II COMPLETED	FEBRUARY 1972
POINT MUGU	003004	FPS-16	VESS INSTALLED	OCTOBER 1968
SAN NICOLAS	013003	FPS-16	VESS INSTALLED	OCTOBER 1968

ADVANTAGES TO BE GAINED BY USE OF DOPPLER RANGE RATE

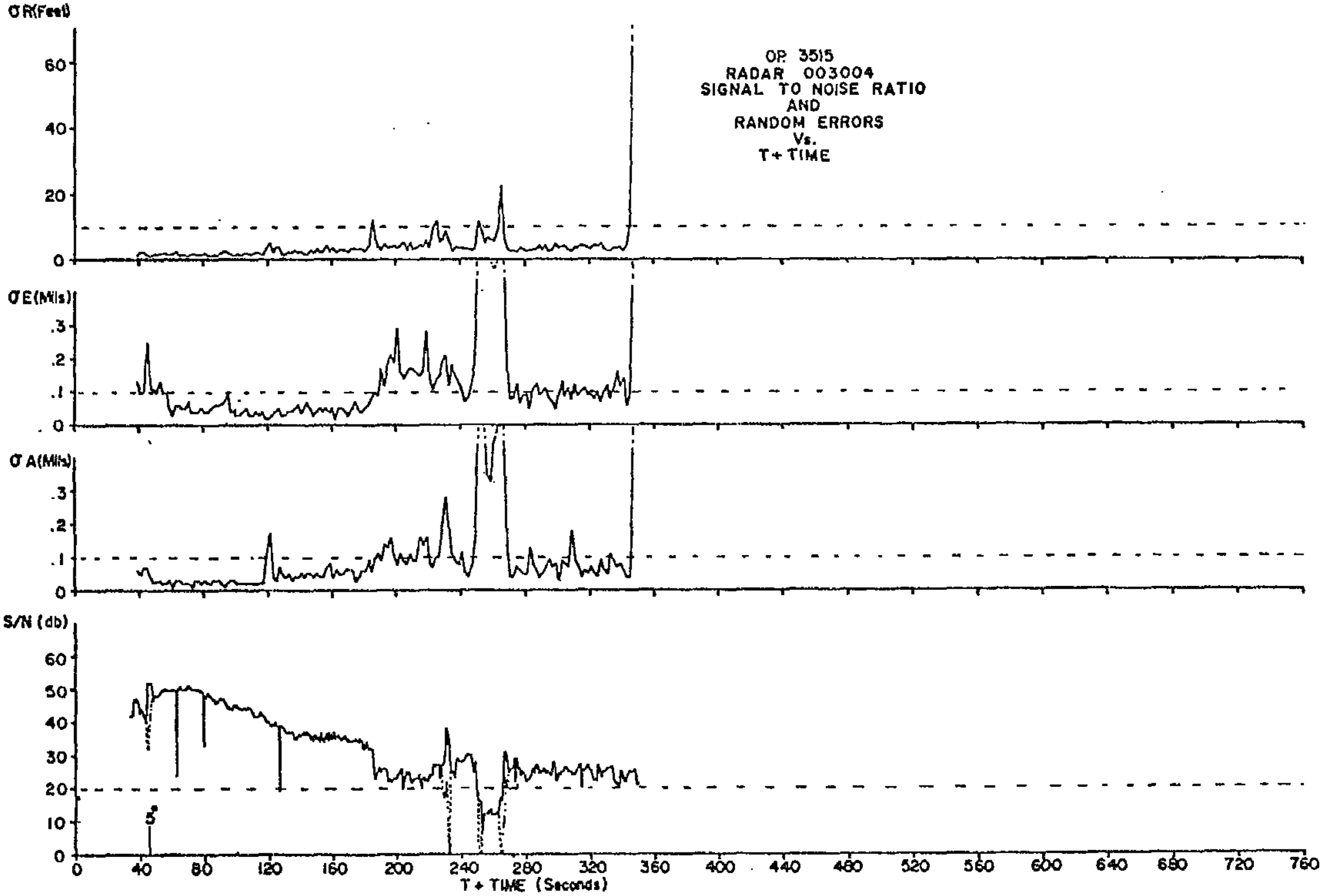
- RANGE RATE DATA HAS VERY LOW RANDOM ERRORS (ABOUT 0.05 Ft/Sec)
- RANGE RATE DATA HAS HIGH ACCURACY (CURRENTLY < 1 Ft/Sec) (0.1 Ft/Sec ACHIEVABLE)
- TARGET VELOCITY WITH IMPROVED ACCURACY AND LOWER GEOMETRIC DILUTION OF PRECISION WITH MULTILATERATION TYPE SOLUTION
- IMPROVED IMPACT PREDICTION
- IMPROVED DATA TO RANGE USERS

SYSTEM PROBLEMS

- LOSS OF DATA DURING THIRD STAGE FOR TPQ-18
- LOSS OF DATA AT STAGING EVENTS
- AMBIGUITY RESOLUTION PROBLEM (6 SECOND MINIMUM)
- INABILITY OF FPQ-6 TO OPERATE AT 640 PRF WITH DOUBLE PULSE CODED BEACON
- ACCELERATION SENSITIVE ERROR IN SAMTEC AND PMR DOPPLER RADARS
- CLUTTER INTERFERES WITH PRE LAUNCH CHECKOUTS AND INITIAL ACQUISITION
- LOW BEACON TRANSMITTER POWER

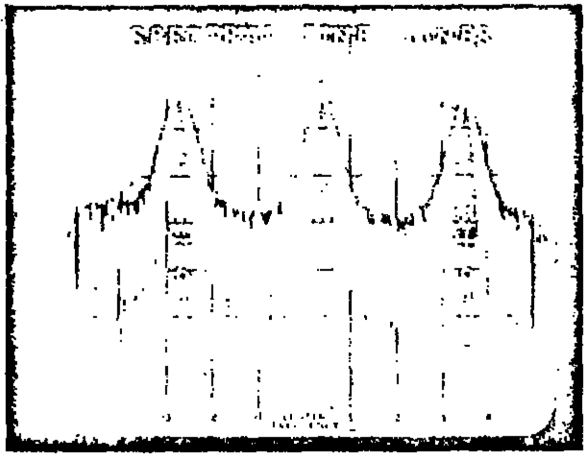


RADAR 003004 SIGNAL TO NOISE RATIO and RANDOM ERROR PLOTS

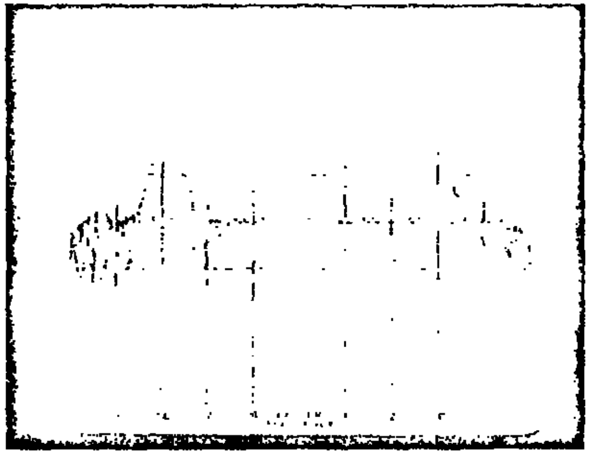

OP 3515
RADAR 003004
SIGNAL TO NOISE RATIO
AND
RANDOM ERRORS
Vs.
T+ TIME

LOSS OF RANGE RATE DATA DURING THIRD STAGE BY TPQ-18

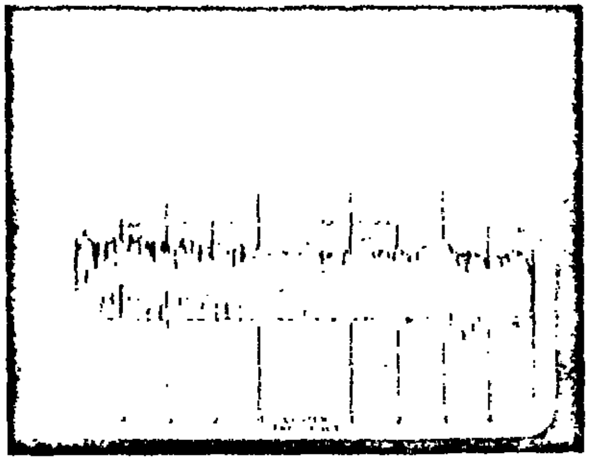
- CAUSE OF PROBLEM IS FLAME MODULATION OF RF SIGNAL
- TPQ-18 PRIMARILY AFFECTED
- ALL RADARS SUSCEPTIBLE IF MISSILE ATTITUDE WERE CHANGED
- 640 PRF REDUCES EFFECT



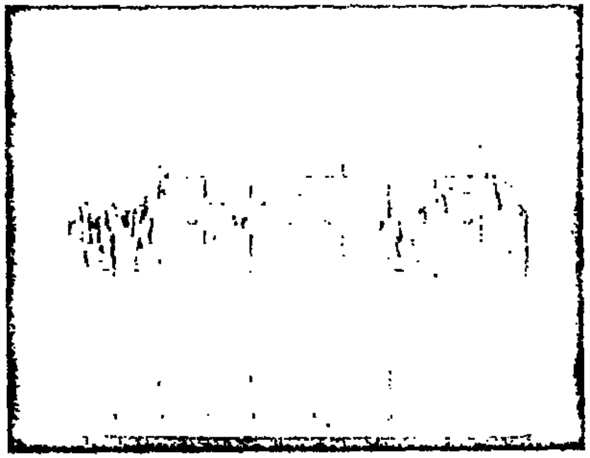
T + 100 Seconds



T + 120 Seconds



T + 165 Seconds

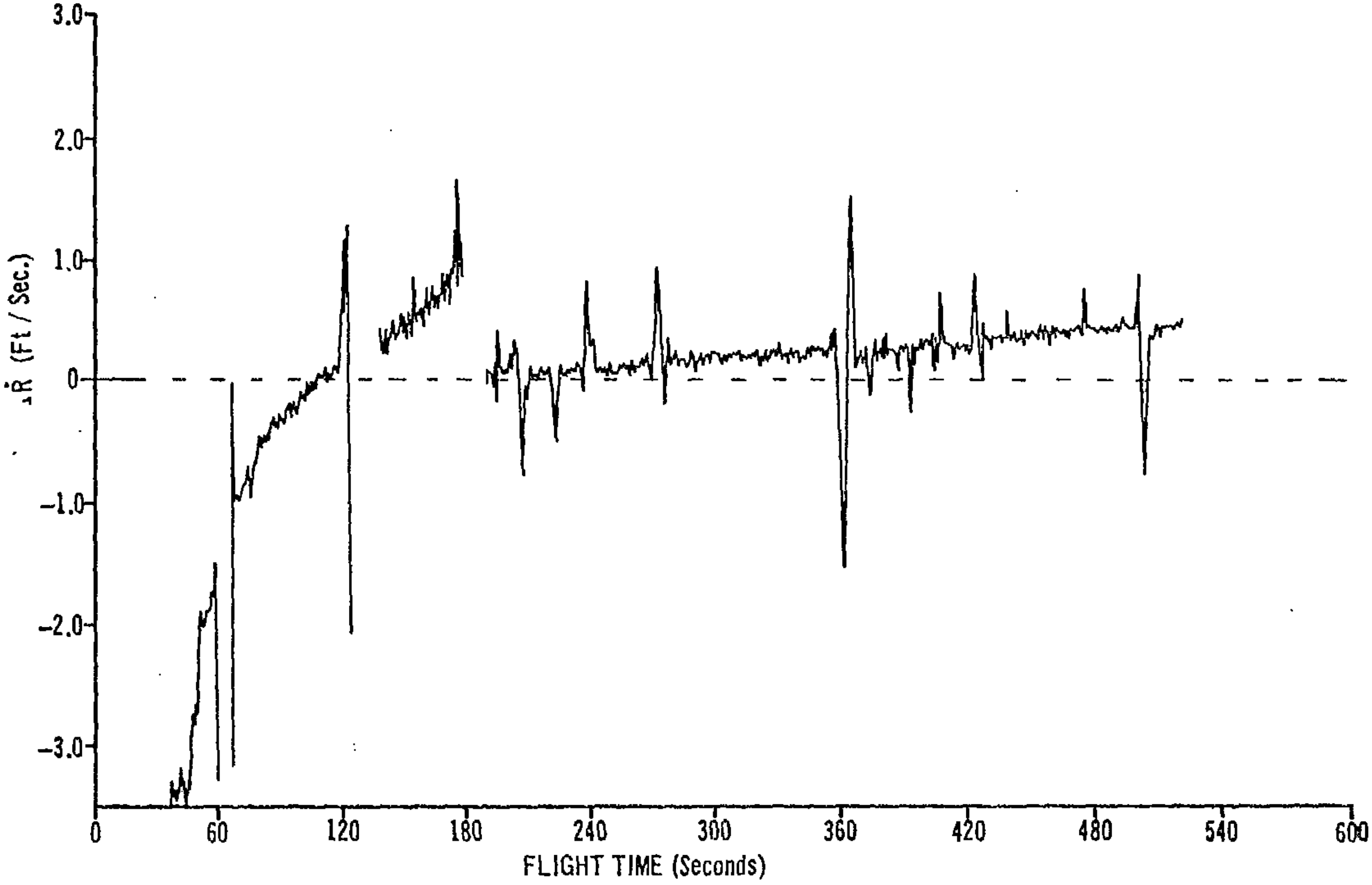


T + 185 Seconds

SIGNAL SPECTRUM
TPQ-18, OP. 3519

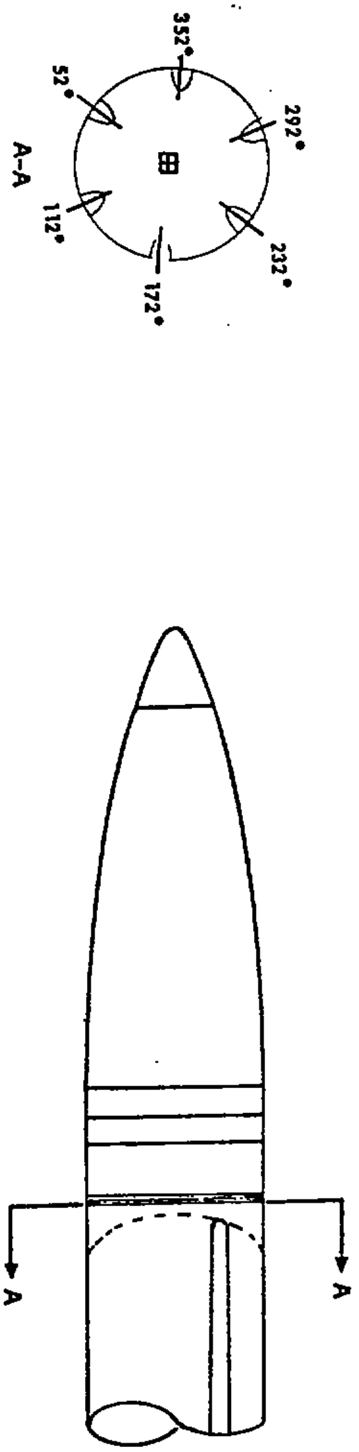
LOSS OF DATA DURING STAGING EVENTS

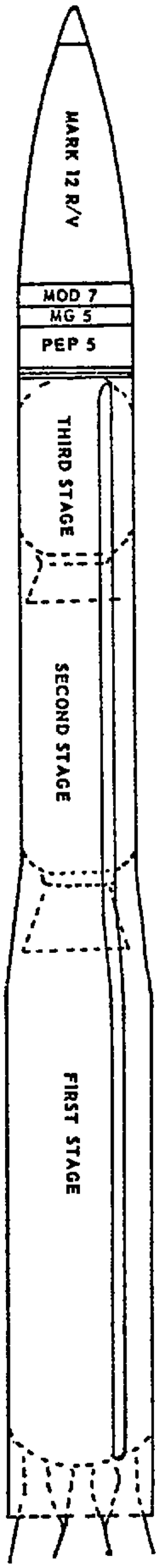
- VEHICLE "JERK" APPEARS TOO LOW TO CAUSE PROBLEM
- FLAME MODULATION APPEARS MOST LIKELY CAUSE
- TELEMETRY SIGNALS DEGRADED AT SAME TIME
- ALL RADARS HAVE OCCASIONALY SEEN PROBLEM
- FPQ-6 UNABLE TO OPERATE AT 640 PRF WITH DOUBLE PULSE CODE BEACON



OPERATION 5179
MODE PBV BEACON

RADAR SNI, FPS-16, SYS. 3
DATE 31 JANUARY 1973


352°
52°
292°
112°
232°
172°
A-A
A
A

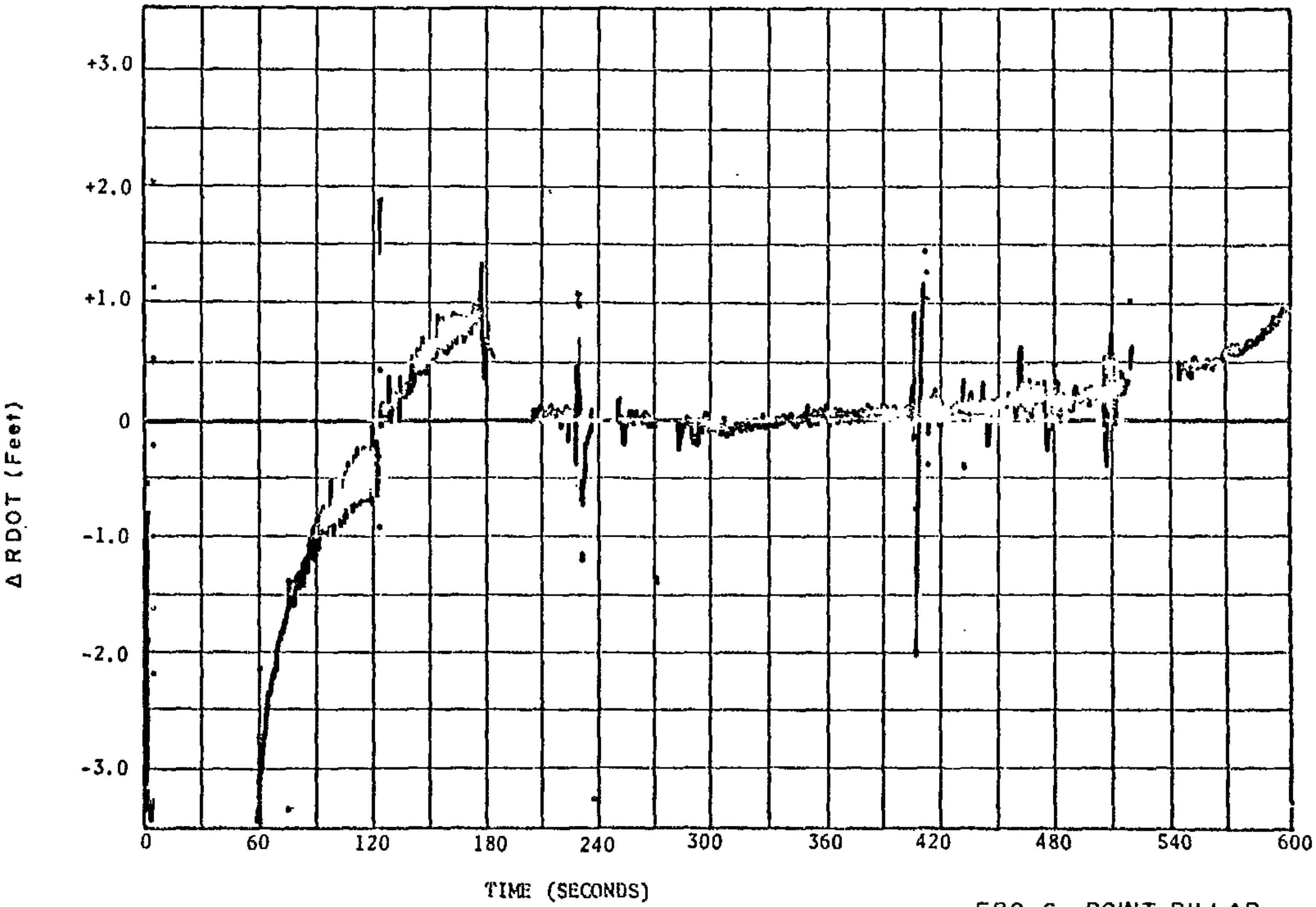

MARK 12 R/V
MOD 7
MG 5
PEP 5
THIRD STAGE
SECOND STAGE
FIRST STAGE

AMBIGUITY RESOLUTION TIME

- 6 SECOND MINIMUM WITH CURRENT MATHEMATICS
- MINOR PROBLEM FOR POSTFLIGHT DATA USE
- MAJOR PROBLEM FOR RANGE SAFETY USE

ACCELERATION SENSITIVE ERROR

- ERROR SIGN, SHAPE, AND MAGNITUDE SAME AS READING VELOCITY LATE
- ERROR DETECTED BY SPAD, TRW, AND AUTONETICS
- CAUSE OF ERROR UNKNOWN
- POSSIBILITY OF ERROR IN INERTIAL GUIDANCE DATA NOT COMPLETELY ELIMINATED



FPQ-6, POINT PILLAR
RADAR 213002, RDOT, RAW

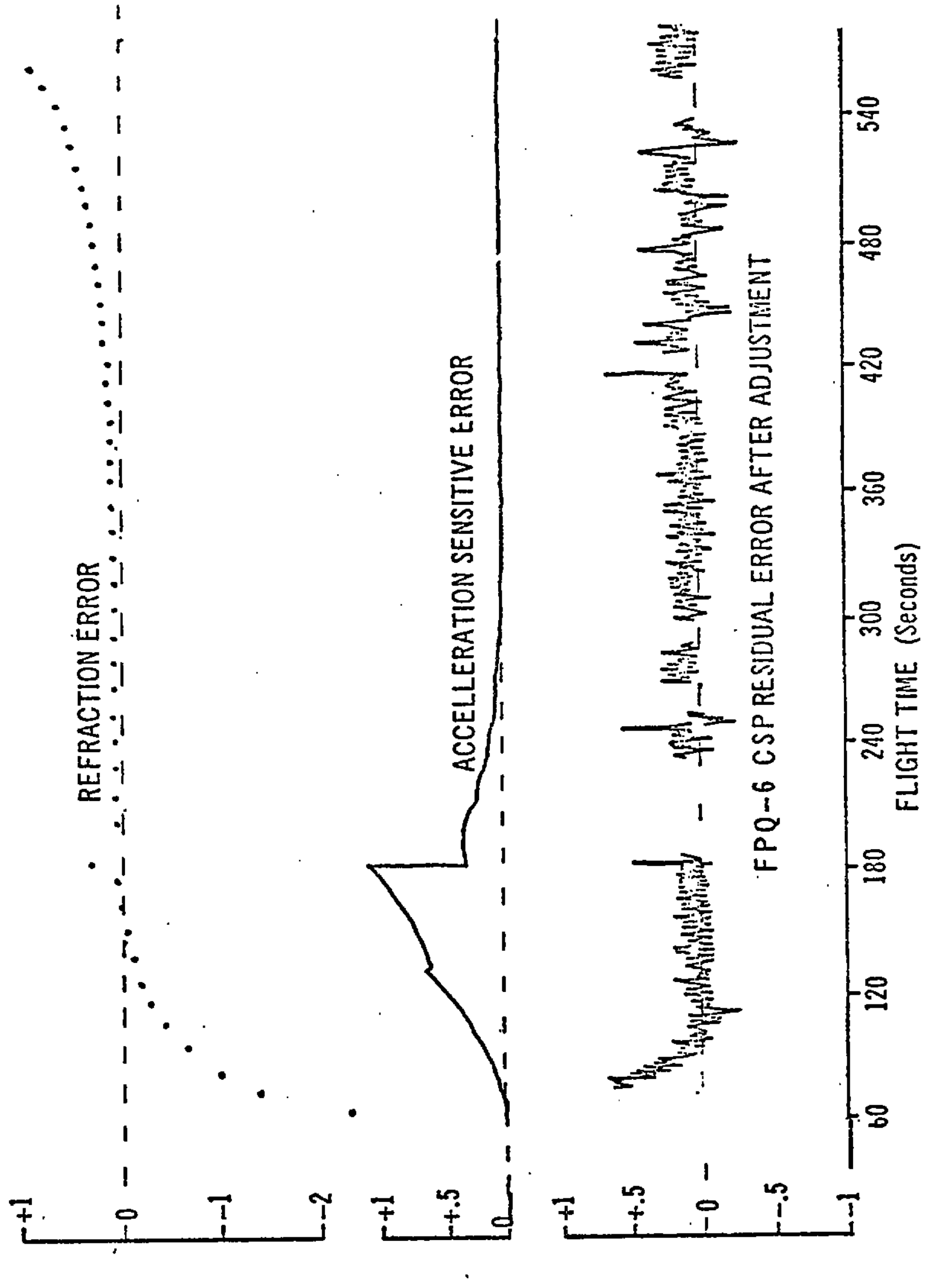
OPERATION 7243

DATE

MODE

1 MIL = .05625 DEGS

RDOT Vs IG (BET AUTO)


REFRACTION ERROR
ACCELLERATION SENSITIVE ERROR
FPQ-6 CSP RESIDUAL ERROR AFTER ADJUSTMENT
FLIGHT TIME (Seconds)
60
120
180
240
300
360
420
480
540
+1
0
-1
-2
+1
+.5
0
+1
+.5
0
-.5
-1

SUMMARY

- PREFLIGHT BIAS DETERMINATION SOFTWARE IS AWAITING CERTIFICATION
- A SOURCE AND FIX FOR ACCELERATION SENSITIVE ERROR SHOULD BE DETERMINED
- FASTER MATHEMATICS FOR AMBIGUITY RESOLUTION SHOULD BE INVESTIGATED
- RANGE RATE DATA CAN BE CURRENTLY FURNISHED WITH LESS THAN 1 FT/SEC ERROR
- 0.1 FT/SEC RANGE RATE DATA CAN BE ACHIEVED WITH A REASONABLE RESOURCE EXPENDITURE

APPENDIX H

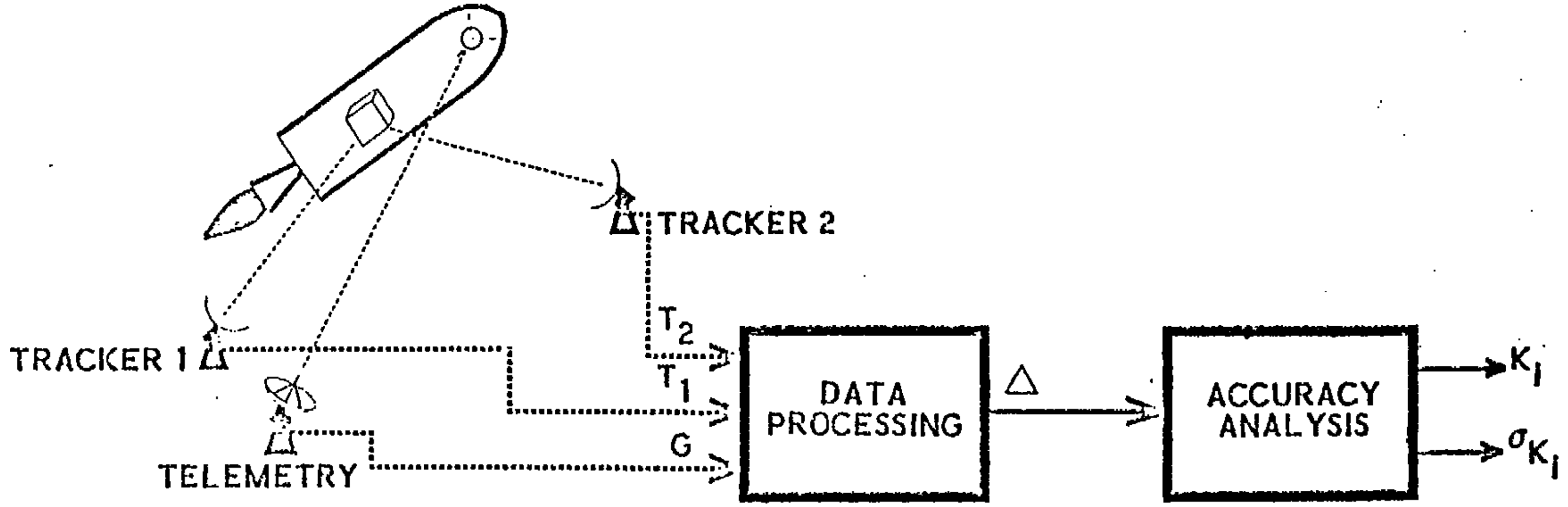
COHERENT TRACKING DATA FOR MINUTEMAN III EVALUATION

By

MAJ. TOM THOMASON, SAMSO
MNNC

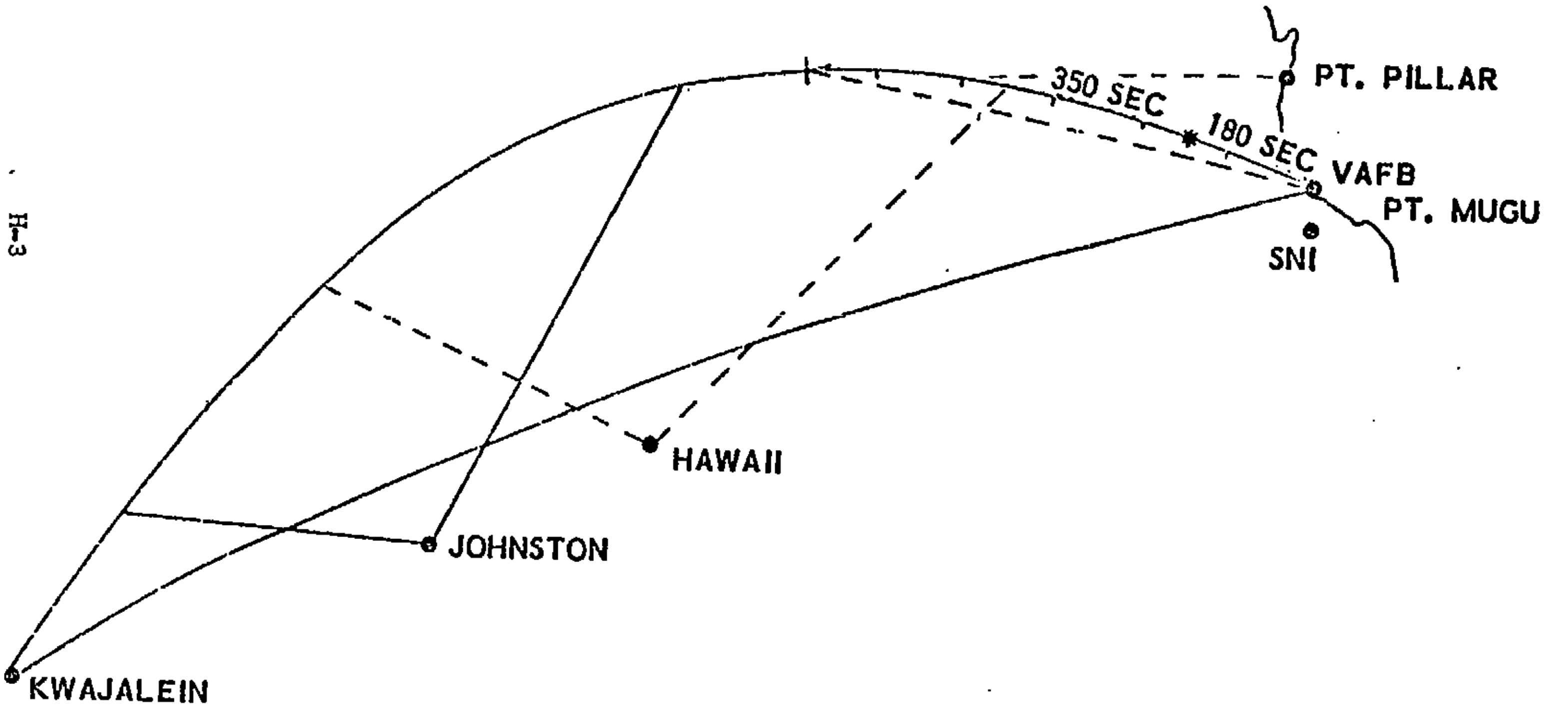
Norton AFB, California 92401

ACCURACY MEASUREMENT FROM FLIGHT DATA


TRACKER 2
TRACKER 1
TELEMETRY
T_2
T_1
G
DATA PROCESSING
$\triangle$
ACCURACY ANALYSIS
K_I
σ_{K_I}

$$\triangle = \underbrace{K_0 t + K_1 V + K_2 \int_0^t a^2\, dt + \ldots}_{\text{GUIDANCE MODEL}} \underbrace{K_3 R + K_4 \cos E + \ldots}_{\text{TRACKING MODEL}}$$

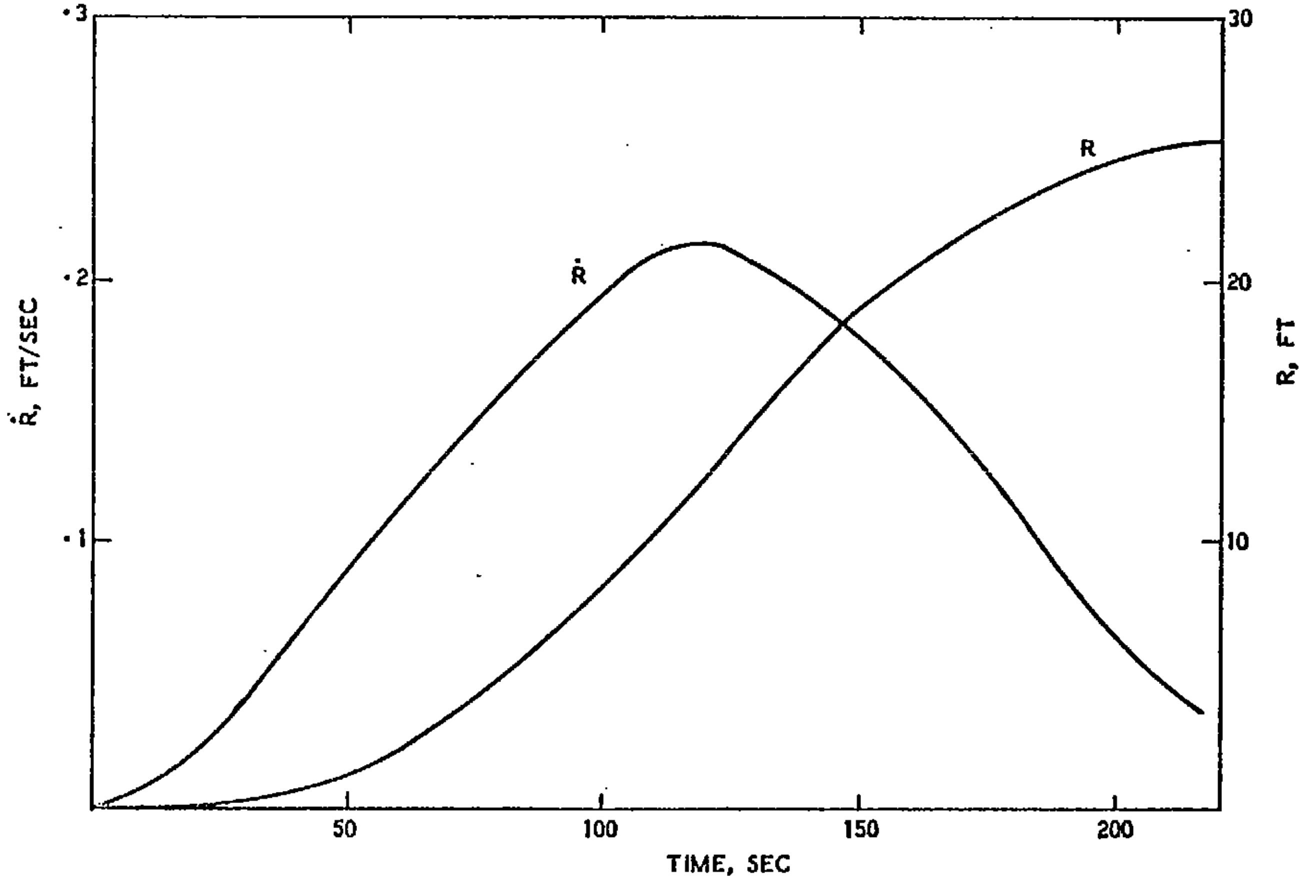
AFWTR RADAR COVERAGE



COHERENT DATA UTILIZATION

- COHERENT DATA IMPROVES FREQUENCY RESPONSE
  - ADVANTAGE OF LIMITED USE FOR GUIDANCE FLIGHT ANALYSIS
  - USEFUL FOR IDENTIFICATION OF GUIDANCE ANOMALIES
  - USEFUL FOR ISOLATION OF CERTAIN GUIDANCE ERROR TERMS
- REAL TIME ACCURACY IMPROVEMENT (RANGE/SAFETY APPLICATION) SIGNIFICANT
- GEOMETRY CONSIDERATION LIMITS USEFULNESS AT AFWTR
- PROVIDES 10 TO 30% POTENTIAL OVERALL IMPROVEMENT FOR GUIDANCE EVALUATION
- PROVIDES INCREASED CONFIDENCE IN EVALUATION RESULTS

PROPAGATION OF GUIDANCE ERROR IN PT. PILLAR RANGE RATE COORDINATES



COHERENT SYSTEM TEST RESULTS

- COHERENT DATA OBTAINED ON RECENT FLIGHTS (STM-7W, PVM-2, -4, -3)
- COMPARISON OF IMU OUTPUT CORRECTED FOR ESTIMATED ERROR* WITH COHERENT DATA YIELDS EXCELLENT MEASURE OF COHERENT QUALITY (COMPARISONS ACCURATE TO ~0.03 FT/SEC RANDOM ERROR; 0.5 TO 0.10 FT/SEC SYSTEMATIC ERROR)

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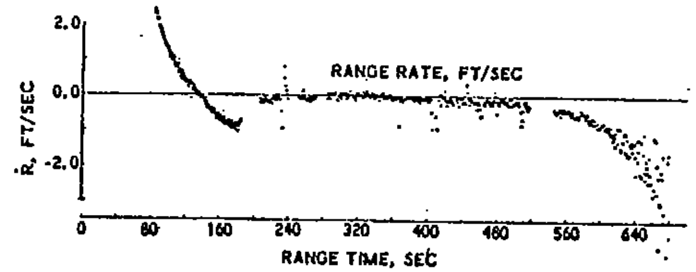
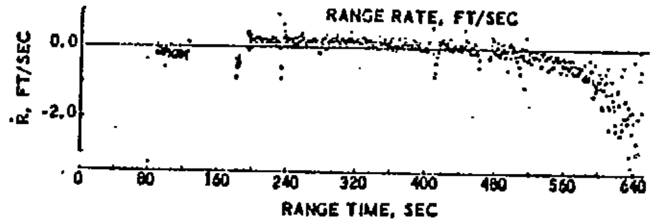
*ESTIMATION BASED ON R, A, E POWERED FLIGHT DATA FROM UPRANGE AND MIDRANGE RADARS.

POSTFIT RESIDUALS FOR STM-7W

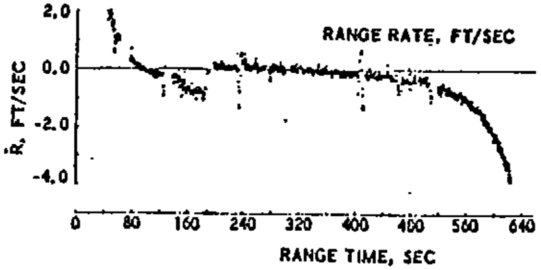
POINT PILLAR 2



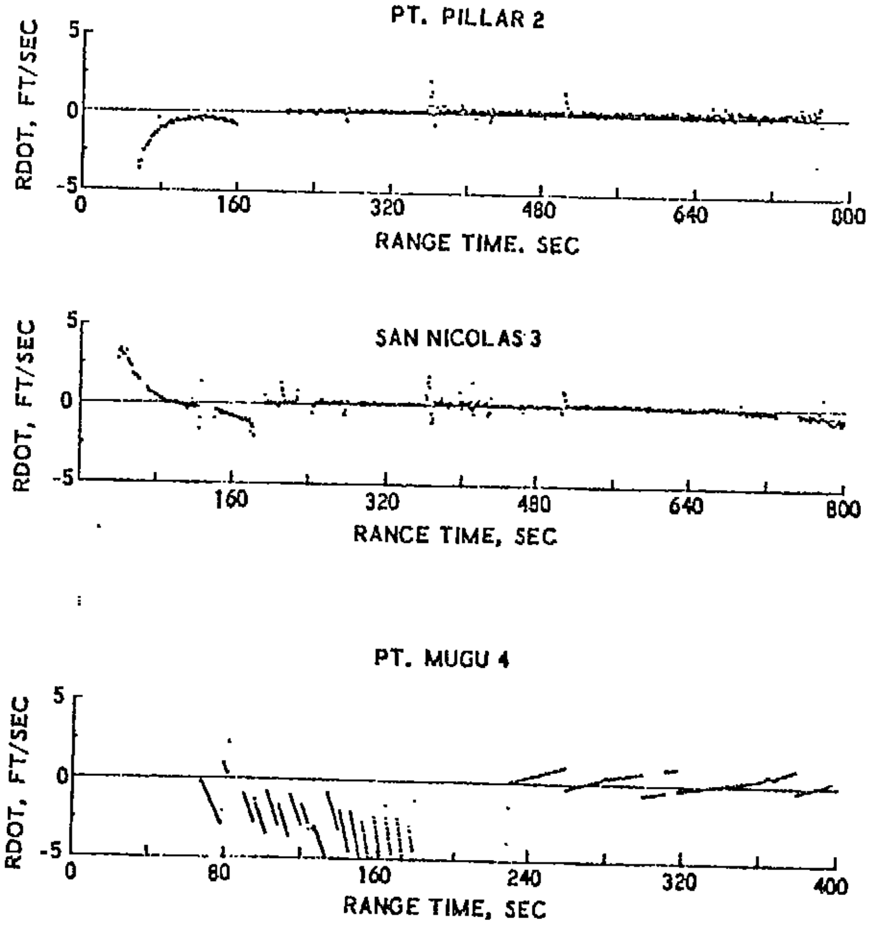
SOUTH VENDENBERG 3



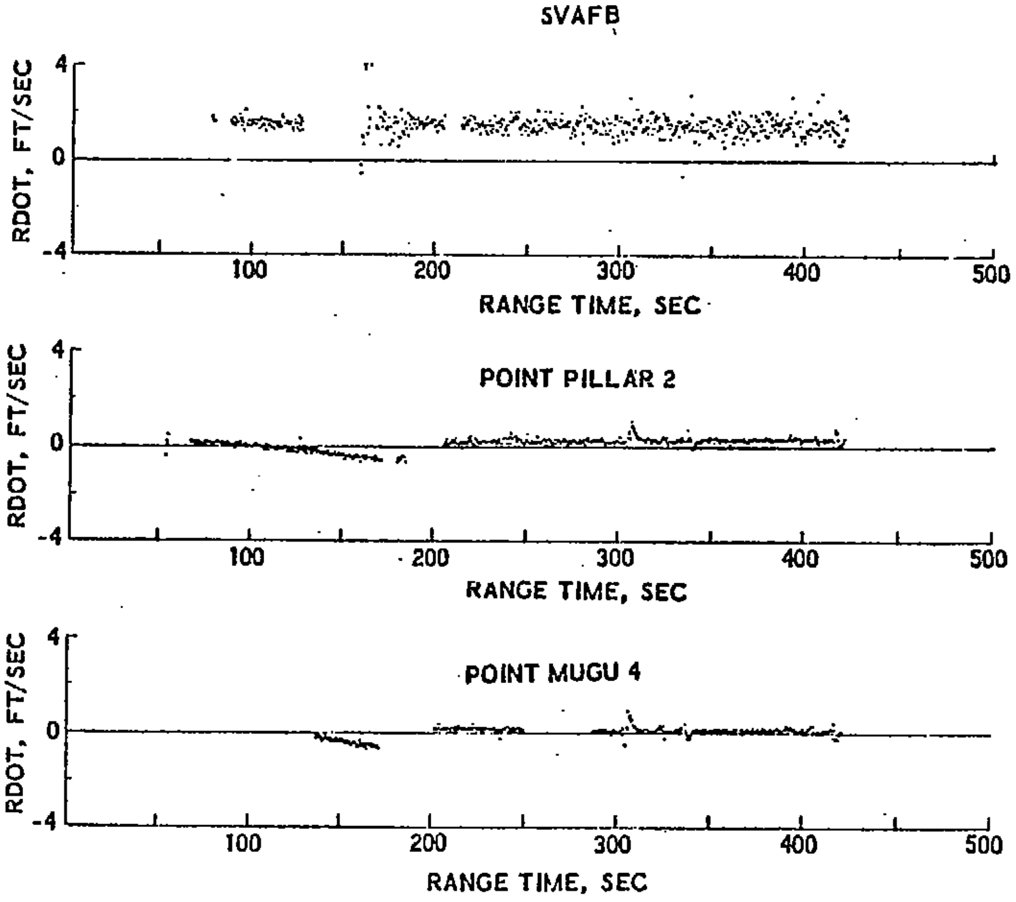
POINT MUGU 4



RDOT RESIDUALS FOR PVM-2

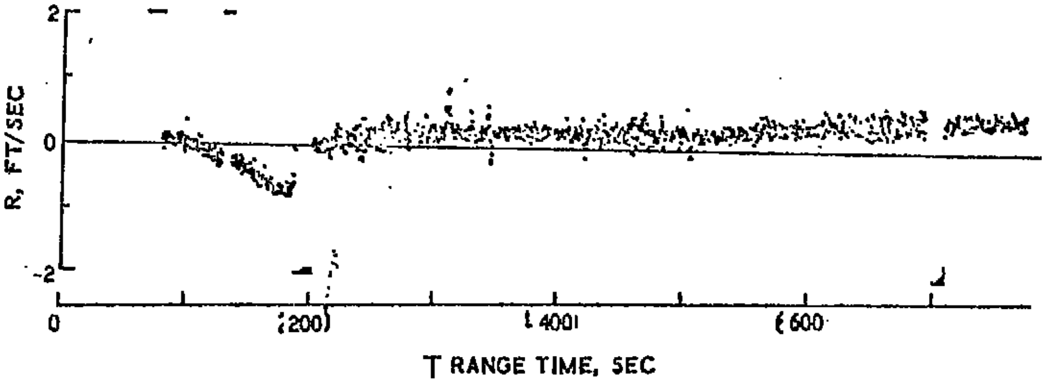


RANGE RATE RESIDUALS FOR PVM-4

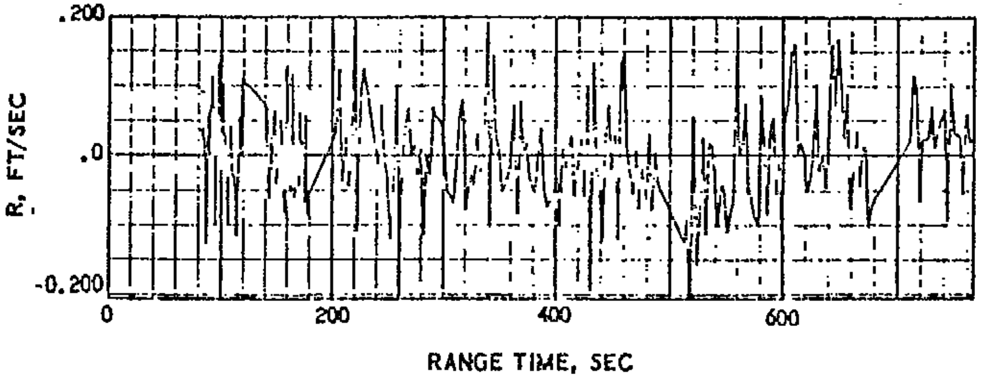


RANGE RATE RESIDUALS FOR PVM-3

PT. PILLAR BEFORE CORRECTION



PT. PILLAR AFTER CORRECTION



SUMMARY

- LARGE SYSTEMATIC ERRORS NOTED IN EARLIER FLIGHT TEST RESULTS ELIMINATED
- RANDOM AND SYSTEMATIC ERRORS IN NON-DYNAMIC PORTIONS OF TRAJECTORY APPROACHING SPECIFICATION ACCURACY LEVELS
- ERRORS OBSERVED IN DYNAMIC OR BOOST PHASE OF FLIGHT MUST BE ELIMINATED TO ACHIEVE EXPECTED OVERALL ACCURACY IMPROVEMENT OF 10 TO 30%
- LIMITATIONS IN POWER OF COHERENT BEACON DEGRADING ACCURACY OF NON-COHERENT MIDRANGE DATA
- LIMITATION IN POWER SUSPECTED OF CAUSING DEGRADATION IN BOOST DATA QUALITY

SUMMARY OF TEST RESULTS

FLIGHT	DATE	RADAR			
		SVAFB 3	PT. PILLAR	SAN NICOLAS	PT. MUGU
STM-7W	8/2/72	0.3 fps IN BOOST-SEVERE REFRACTION ERROR	2 TO 4 fps BOOST ERROR (TIMING SUSPECTED) PLUS 2 TO 3 fps REFRACTION ERROR	N/A	SIMILAR TO PT. PILLAR
PVM-2	1/31/73	N/A	REFRACTION ERROR CORRECTED, BUT 3 fps POWERED FLIGHT ERROR	3 fps POWERED FLIGHT ERROR	50 fps ERROR (MISSED AMBIGUITY SLOT)
PVM-4	6/1/73	1 fps NOISE 2 fps BIAS	POWERED FLIGHT ERROR < 0.3 fps, NOISE ~ 0.1 fps	N/A	SIMILAR TO PT. PILLAR
PVM-3	8/24/73	N/A	~1 fps POWERED FLIGHT ERROR	N/A	N/A

APPENDIX I

PROBLEMS ASSOCIATED WITH DEVELOPMENT OF A LAUNCH HEAD RANGE SAFETY SYSTEM FOR CONTAINING ICBM LAUNCHES IN THE KWAJALEIN LAGOON CORRIDOR

By

STAN RADOM
SAMTEC-CA

Space and Missile Test Center
Vandenberg AFB, California 93437

PROBLEMS ASSOCIATED WITH DEVELOPMENT OF A LAUNCH HEAD RANGE SAFETY SYSTEM FOR CONTAINING ICBM LAUNCHES IN THE KWAJALEIN LAGOON CORRIDOR

Stan Radom, SAMTEC

(Verbatim Transcript from Tape)

I am using a viewgraph made in 1966 in order to give you an idea of why we got into coherent tracking in the first place. There's some interesting history attached to it. I'd like to go over briefly why the very large expenditures were made here, San Nicolas Island, Pillar Point, and Point Mugu to get into the range and range rate business.

When the Western Test Range was formed, the Air Force took over PMR responsibilities for instrumentation of ballistic launches and space launches from the west coast. The Electronics System Division of the Air Force was assigned the task of attempting to outguess our needs. They were going to tell us what we were going to need to accomplish our objectives.

Back in about 1966 there was a detachment of ESD people here. When they took a look at this problem they said, "Yes, you are suffering from a lack of downrange islands so something drastic has to be done." The requirement was thrust upon us to start impacting ICBMs in the Kwajalein area. That was because a great deal of money was being spent in the Roi-Namur complex for TRADEX and other radars associated with evaluation of reentry systems. Then they added the requirement to score impacts, and recover warheads. The recovery dictated the need for the lagoon impacts. They not only wanted an accurate score, they also wanted to get the warhead (or pieces) back. That dictated negotiation with the Marshallese to evacuate a corridor 32 miles wide through the middle of the Kwajalein lagoon.

(See Viewgraph)

This basic problem and why I brought it up, points out the need and justifies the expenditure for the coherent modifications to the FPQ-6 at Pillar Point and the FPS-16's at PMR. The TPQ-18 was already programmed for coherent mod by the ETR before it was delivered to Vandenberg.

So this is generally the problem. A much different situation because you have natives, plus military and civilian dependents on Kwajalein and you have a population up at Roi-Namur. This was drastically different than the situation at Eniwetok where there were no natives, no dependents, and where shelter was provided for all essential personnel. It was a good place to do extra-hazardous testing. At that time we had developed an underwater scoring system for the Eniwetok lagoon that exceeded our expectations, and we had a 1 Sigma circular accuracy of 34 feet on impacts. Of course, you can't argue when the recovery barge is vectored into position, and the diver dives down about 200 feet and steps on the warhead! But with this requirement at Kwajalein, we had to do something drastic, so, ESD initiated a study with the help of MITRE, to see if multilateration radars bearing down on the trajectory might provide a range safety system that could contain the impacts in the corridor without inadvertent destruction of good missiles.

So we took a look at what the geometrical configuration could do. We had some simulation software; we had a contract with RCA to take a look at this situation, along with the work being done by ESD, and what little work we did in-house at the time. This generally is what the situation looks like.

(First Overlay)

With a single FPS-16 at the launch head, and a computer, you have an uncertainty of something like 42 miles, bigger than the corridor itself – its just out of the question! The future impact prediction was just not useful. There was no question but that it was inadequate. The multilateration mode, that I'm going to show you here, closely correlates both the ESD study and RCA analysis, and what everyone took a look at.

Lets take a look at adding radars, and, although we don't have downrange islands, lets see what we can do with bilateration.

(Next Overlay)

This reduced the IIP uncertainty in order of something like 10 miles. Still unsatisfactory - it didn't allow enough latitude for the excursion that a MINUTEMAN, for example, might make in the last few seconds of powered flight. Adding another sensor – if you had conventional pulse radars, Point Pillar and San Nicolas Island giving you the longest baseline for bilateration plus trilateration, using a ship providing a data link, as you can see you then have an uncertainty elipse that looks like your improving things. Of course, the ship can give you the Z-component, measuring altitude in an optimum position near burnout. Of course, its the Z-component when you go a quarter of the way around the earth, 4300 miles to the target area at Kwajalein, thats your major source of error. So you can see why there was a dramatic improvement here, but it was still not satisfactory. The risk would be too great to say that, if we had conventional pulse radars, bilateration, plus a ship and real time. So then we took a look at what range and range rate would do for you.

(Next Overlay)

As soon as you went coherent in a bilateration mode, when reading range and range rate directly, you can see that the size of the uncertainty ellipse narrowed down, moved about 90 degrees. But when you're bouncing back and forth against the corridor lines, it still hasn't done enough good.

Lets take a look at what happens when you put a ship in the solution. This is a ship near burnout with a conventional pulse radar, but providing real-time data reliably into the computation center. It reduces your uncertainty ellipse to something like 2 by 3 miles. And that looks good! Theory showed that this is the way to go!

Lets go coherent at Point Pillar and give the Navy the money to modify radars at San Nick, Point Mugu, and away we go!

In those days we had ships also. This convinced the people reviewing the budget, and everyone else, that this was a sound method of approach. All the problems you've been hearing about, some of the presentations that our folks have shown you, kept talking about the IIPs and Kwajalein, this was the compelling requirement. The problem has been taking the theory and reducing it to practice.

As in MINUTEMAN, the problem of having a range safety system for a multi-stage solid rocket, with high accelerations is that it requires that action be taken in the last half-second of powered flight. You have to measure lateral acceleration near burnout to reliably contain the impact within the boundaries of the Kwajalein lagoon corridor. That means you are going to have to have computer abort. You can't have a guy at a console with his finger on a button. The brain-to-finger response time alone is out of the question.

As soon as we started talking about computer abort, the Range Commander who has the safety responsibility and can't delegate it, asked the great question: "How reliable is my system, what is the possibility of that computer blowing a good 'bird'?"

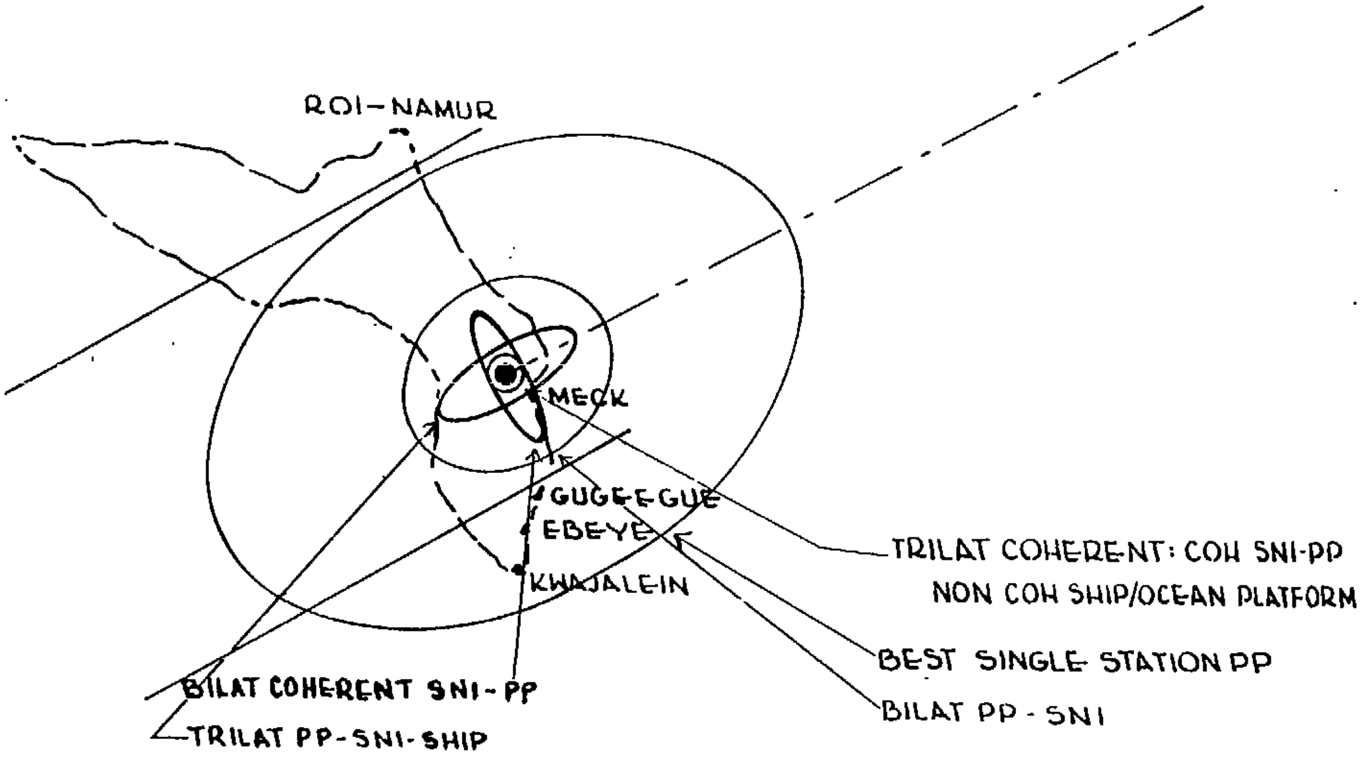
So, my small analysis group started looking at reliability figures for radars in general, data links, everything associated with getting the data into the computer. Assuming that we had the software that worked at the time, what were the chances of a dropout that would cause a computer abort? It turns out that the Range Safety Officer would buy about 5 percent of the birds. So, each Commander, when given that information, said "I'm going to take my chances, I don't want computer abort. I'd rather go with the waiver before I design into the system an assured method of blowing 1 out of 20 'birds'." Generals Bleymaier, Kronauer, Wilson and Lowe felt the same way. We haven't had a Commander who has felt differently. As a result, this kind of put the haitus on where we were going with this system. Furthermore, we didn't have the computational power, as an example, even if we had a system that could work reliably. Because we did not demonstrate a positive system of range safety, we couldn't tell our users, "you must carry a coherent beacon."

That is essentially where we are today, and one of the reasons for this conference. We have coherent mods. We know a lot more about beaconry and we know a lot more about the reliability of data links. So we need another appraisal - maybe an agonizing reappraisal of whether we're going to take another stab at this system, take a look at GERTS for MINUTEMAN, or whatever means we can. Maybe an interferometric system? I'm not talking about a floating MISTRAM or something like that, but by taking another look at whatever technology is available to us, so we can go from the waiver mode to a positive system of range safety for Kwajalein.

I hope that this briefing will give you some background on why the initial investment was made in coherent radars for the West Coast launch head.

WTGT-67-3

INSTRUMENTATION IIP ACCURACY



APPENDIX J

PULSE DOPPLER INSTRUMENTATION RADARS

By

RENZO MITCHELL, RCA

MSRD, Bldg. 108-239
Moorestown, New Jersey 08057

PULSE DOPPLER INSTRUMENTATION RADARS

Renzo Mitchell, RCA

FPQ-6/TPQ-18

VAFB
PILLAR POINT
WALLOPS ISLAND

FPS-16

PT. MUGU
SAN NICOLAS

MPS-36

2 – SAMTEC (MRSS)

1 – TONOPAH

2 – KWAJALEIN

3 – GERMANY

6 – WSMR

DESIGN PERFORMANCE CAPABILITY

FPQ-6/TPQ-18

RANGE RATE	0.1 FT./SEC.

COHERENT INTEGRATION IN RANGE AND ANGLES

FPS-16

RANGE RATE	0.1 FT./SEC.
MPS-36	1.0 FT./SEC. (SPEC.) 0.1 FT./SEC. DESIGN CAPABILITY

MPS-36 FINE LINE TRACK

FINE LINE TRACK IN RANGE AND ANGLES.

DECREASED DOPPLER AMBIGUITY RESOLUTION TIME.

CAPABILITY OF TRACKING THROUGH CLUTTER.

IMPROVEMENTS IN CAPABILITY

.....SOFTWARE ENCHANCEMENT TO MAINTAIN DOPPLER TRACK DURING STAGING.

.....SOFTWARE ENHANCEMENT TO MAINTAIN DOPPLER TRACK DURING EVENTS THAT CAUSE SPECTRAL SPREADING – FLAME EFFECTS.

.....SATELLITE COMPUTER TO RELIEVE 4101 OR DDP-124.

.....AUTO CHECKOUT TO ASSURE OPERATIONAL READINESS.

.....VELOCITY/ACCELERATION PROCESSING IMPROVEMENTS TO ENHANCE INITIAL LOCK–ON CAPABILITY AT LOW PRF AND HIGH ACCELERATION.

.....DRIVER STROBE RISE–TIME REDESIGN.

.....SYSTEM NOISE FLOOR IMPROVEMENTS.

APPENDIX K

GEOS-C PROJECT DESCRIPTION

By

H. R. STANLEY

NASA/Wallops Station
Wallops Island, Virginia 23337

GENERAL PROJECT DESCRIPTION

The purpose of the GEOS-C Project is to design, develop, and launch a geodetic and oceanographic satellite and to perform experiments in support of the application of geodetic satellite techniques to the Earth and Ocean Physics Applications Program.

The GEOS-C Mission will provide data with which to refine the geodetic and geophysical results of the National Geodetic Satellite Program (NGSP) and will furnish a test bed for new systems. This Mission will also contribute to fulfilling the C-band radar calibration and altimeter requirements of the Departments of Defense and Commerce.

The spacecraft for this mission was designed and fabricated by the Applied Physics Laboratory of the Johns Hopkins University. The structural configuration is based on the GEOS-2 mechanical design. Basically, the structure will be the same as GEOS-2 with the substitution of heavier trusses to accommodate the additional weight.

The GEOS-C (Geodynamics Experimental Ocean Satellite) will be launched during FY-75 from the Air Force Western Test Range (AFWTR) located at Vandenberg AFB, California. The nominal orbit parameters are:

Mean Altitude - 843 km
Inclination - 115 degrees
Eccentricity - 0.006
Period - 101.8 minutes

The orbital parameters are chosen to maximize the possibility of providing orbit traces which cover the earth's surface in a prescribed grid work pattern,i.e., 1° x 1°.

Following orbital injection, the spacecraft will employ an attitude stabilization system consisting of a gravity gradient boom with end mass and damper, momentum wheel and an electromagnet. The energized electromagnet creates a magnetic dipole moment along the boom axis of the satellite to aid in gravity gradient capture. The axis will align with the earth's magnetic field so that in the northern latitudes the proper side of the spacecraft will point earthward. At this time, the boom will be extended and the electromagnet turned off.

Power for operation of the spacecraft and experiment sub-systems will be provided by a single 11-cell battery. The battery will provide a 14.7 volt nominal power supply for the duration of the mission which is scheduled for a period of one year.

A PCM/PM telemetry system will allow two basic modes: low bit rate data transmission (1.562K bits/sec) or high bit rate data transmission (15.62K bits/sec.). Transmission of data will be either via S-band direct to ground, S-band to ground via the ATS-F satellite, and/or VHF direct to ground. Experiment sub-systems will be controlled by a series of commands either stored (delayed command) or sent directly from ground stations.

GEOS-C MISSION OBJECTIVES

The GEOS-C Mission Objectives in order of priority at launch are:

- To perform an in-orbit satellite altimeter experiment to: (1) determine the feasibility and utility of a space-borne radar altimeter to map the topography of the ocean surface with an absolute accuracy of ±5 meters, and with a relative accuracy of 1-2 meters, (2) determine the feasibility of measuring the deflection of the vertical at sea, (3) determine the feasibility of measuring wave height, and (4) contribute to the technology leading to a future operational altimeter-satellite system with a 10-cm measurement capability.

- To further support the calibration of NASA and other agencies' ground C-band radar systems by providing a space-borne coherent C-Band transponder system, to assist in locating these stations in the unified earth-centered reference system, and to provide tracking coverage in support of the radar-altimeter experiment.

- To perform a satellite-to-satellite experiment with the ATS-F satellite using an S-Band transponder subsystem to directly measure the short period accelerations imparted to the spacecraft by the gravity field and to determine the position of the spacecraft. The anticipated measurement data quality of about .04 cm/sec over a ten-second integration interval will aid in improving the earth gravity model up to spherical harmonic terms of degree and order to approximately 25 and in providing tracking coverage over mid-ocean areas to support the radar-altimeter experiment. The satellite-to-satellite system will also be used for altimeter-data relay through AFS-F.

- To further support the intercomparison of new and established geodetic and geophysical measuring systems including: the radar altimeter, satellite-to-satellite, C-Band, S-Band, laser, and doppler tracking.

- To investigate solid-earth dynamic phenomena such as polar motion, fault motion, earth rotation, earth tides, and continental drift theory with precision satellite tracking systems such as laser and doppler ground stations.

- To further refine orbit-determination techniques, the determination of interdatum ties, and gravity models with a spacecraft equipped with laser retroreflectors, C-Band and S-Band transponders and doppler beacons.

- To support the calibration of S-Band sites in the STDN by furnishing a space-borne transponder, to assist in positioning the network stations in the world reference system, and to assist in evaluating the system as a tool for geodesy and precision orbit determination.

The achievement of these objectives not only will constitute a successful mission but also will greatly enhance man's understanding of the physical properties of the planet Earth.

EXPERIMENT PACKAGE

The GEOS-C experiment package will consist of five basic instruments each of which will contribute to one or more of the mission objectives. Consistent with these objectives, the experiment sub-systems are listed in priority order as follows:

Radar Altimeter
Coherent C-Band Transponder
S-Band Instrumentation for Satellite-to-Satellite Experiments
Laser Retroreflector

Doppler Transmitters
Non-Coherent C-Band Transponder
S-Band Instrumentation for Earth Tracking Experiments

Radar Altimeter

The basic objectives of the radar altimeter experiment are to demonstrate the feasibility of utilizing an on-board altimeter to measure the time-varying behavior of the ocean's surface and the departure of the sea surface from the geoid and to investigate altimeter instrumentation technology. To meet these objectives, the altimeter will have two distinct data gathering modes: Long Pulse and Short Pulse. The basic measurement goals established for the altimeter are as follows:

Precision: Short Pulse Mode 30 cm
Long Pulse Mode 60 cm

Geoid Accuracy: Absolute ± 5 meters
Relative ± 2 meters

Sea State: 25% of S.W.H.

One of the primary goals of the experiment will be to obtain engineering data on altimeter performance. For this, it will be necessary to measure and evaluate parameters such as sea-surface roughness and spacecraft libration as it relates to hardware performance. Another goal will be to calibrate the altimeter over an ocean area. The presently planned calibration area will be the portion of the Atlantic Ocean bounded by Wallops Island, Virginia; Merritt Island, Florida; Grand Turk; and Bermuda. Altimeter accuracy will be determined by comparing the altitude measured by the altimeter to the spacecraft altitude determined by independent tracking systems. Precision and resolution will be determined by comparing sea surface profiles resulting from altimeter measurements to profiles determined by independent methods.

C-Band System

Two C-Band radar transponders will be flown on the GEOS-C satellite to support the altimeter and C-Band system calibration as well as geometric, gravimetric, and other geodetic investigations. The C-Band System consists of the two transponders (one coherent and one non-coherent) and the associated ground tracking C-Band radars.

The non-coherent transponder, operating in conjunction with existing ground radar systems, will provide for range and angle measurements. The coherent transponder, operating in conjunction with existing coherent ground radar systems, will provide for range, range rate, and angle measurements.

Laser System

The Laser System consists of the GEOS-C spaceborne laser retroreflector subsystem and the ground-based Laser Ranging Systems. The retroreflector will be utilized in conjunction with the ground-based laser systems to obtain precision satellite ranging data.

In the GEOS-C time frame, the NASA Laser Ranging Systems are expected to have a ranging capability of 10 cm or better. The capability of the angle data is estimated to be about 0.5 milliradian or better. Range and angle data are provided at a once-per-second rate.

Doppler System

The Doppler System consists of two spaceborne transmitters and ground doppler receiving stations. The dual frequencies (162 and 324 MHz) originate from an ultra-stable 5 MHz oscillator.

Ground observation stations measure the doppler components of the signals received from the GEOS-C spacecraft by counting cycles resulting from the difference between the received frequency and the station oscillator. The difference frequencies between the higher and lower received frequencies and the station oscillator are combined in the proper proportions to obtain both the first order ionospheric refraction correction and the refraction corrected doppler frequency.

S-Band System

The S-Band system consists of the following elements:

GEOS-C Coherent S-Band Transponder
GEOS-C S-Band Antenna System
ATS-F Spacecraft
ATS-F Ground Terminals
STDN S-Band Ground Stations

MISSION PROFILE

The GEOS-C Mission has been divided into two distinct phases. Phase I covers all activities from launch through one year of Experiment data collection and Phase II covers those activities after Phase I through the remainder of the Mission lifetime.

Phase I can be sub-divided into several phases according to the extent of experiment data collection, the type of data being collected, and various other operational and physical constraints. These sub-phases along with the dominant activity are:

PHASE I PERIODS	TIME PERIOD (Days After Launch)	DOMINANT ACTIVITY
Phase A	0 - 40	Launch and Operational Assessment
Phase B	40 - 130	Experiment Systems Calibration & Evaluation
Phase C	130 - 285*	Unique Experiments and Localized Grid Activity
Phase D	285*- 325*	Global Activities
Phase E	325*- 405	Localized Grid Densification

* The length of Phase D is not expected to change. However, the time of occurrence is dependent upon the time of ATS-F drift.

PHASE A - Launch and Operations Assessment

This phase begins with Launch and extends over a period of approximately 40 days in which the following activities occur:

(a) Launch

(b) Orbit injection

(c) Early orbit determination and refinement

(d) Gravity gradient capture and damping

(e) Momentum wheel turn on

(f) Yaw capture and stabilization damping

(g) Spacecraft functional and electrical checkout

(h) Operational assessment of experiment systems

It is not expected that any useful experiment data collection will be accomplished during Phase A.

PHASE B - Experiment Systems Calibration and Evaluation

It is expected that this phase will begin about 40 days after launch and continue for two or three months. It is expected that the bulk of the data collected during this period will be useful for investigation purposes. However, data distribution during this period will be slower than normal due to the more detailed analyses required to calibrate all experiment systems and to validate all data processes.

Major activities associated with this phase include the following:

(a) Altimeter experiment systems calibration

(b) Satellite-to-satellite experiment systems calibration

(c) Altimeter experiment systems operation globally,within the real-time ground TM station coverage areas, on those days not utilized for Altimeter Calibration activities.

(d) Ground tracking system (Laser, C-Band and Doppler) data collection activities on a global basis to the maximum extent possible commensurate with power budget, other systems calibration activities, and investigator needs.

PHASE C - Unique Experiments and Localized Grid Activities

Phase C activities are expected to begin approximately 130 days after GEOS-C launch and continue until ATS-F is maneuvered from the Western Hemisphere location (94 degrees west longitude) to the Eastern Hemisphere location (34 degees east longitude).

It will be seen that the transition between Phase B and Phase C will not constitute a major change in the type of activities being conducted, rather only the level and extent of most activities will be reordered.

A typical day during this time period will consist of:

Ground tracking systems (Laser, C-Band and Doppler) data collections activities on a global basis to the maximum extent possible commensurate with power budget, other systems activities, and investigator needs.

Altimeter experiment data collection activities commensurate with power budget, investigator needs and globally within the constraints of the ground TM station coverage.

In addition to this major activity, intermittent calibration and evaluation activities will be conducted at a nominal rate of once per month.

PHASE D - Global Activities

Phase D activities will be conducted during the time in which ATS-F is being maneuvered from the Western to the Eastern Hemisphere.

During this period, four arcs of SSE data per day will be scheduled for a total of 160 SSE data arcs. Each arc will be about 45 minutes long (i.e., compatible with the period of mutual visibility between ATS-F and GEOS-C).

The SSE arcs will be scheduled to provide a complete 5° X 5° grid pattern within the ATS-F coverage areas. This will be accomplished by selecting two consecutive ascending and two consecutive descending passes per day (spaced about 12 hours apart so that they cross near the equator), and basically following these passes each day until the grid is complete. Arc selection as described above, will effectively accomplish the 5 degree gridwork since GEOS-C ground traces are offset by about 5 degrees to the east per day.

In addition, interface with ATS-F during the entire 40-day period should allow a redundant 5-degree grid pattern (offset by about 2 degrees to the east) to be placed in an area extending about 100 degrees in longitude. This additional 5-degree pattern will be placed approximately midway within the ATS-F coverage area (e.e., between approximately 80 degrees west longitude and 20 degrees east longitude).

During each of the SSE arcs described above, radar altimeter data will be scheduled over most portions of the arcs which are over ocean areas. Therefore, a 5-degree gridwork of altimetry data will be collected simultaneously with the SSE data. In addition, C-Band, laser, and doppler data will be scheduled to support orbit determination for the SSE and radar altimeter data arcs scheduled during this period.

PHASE E - Localized Grid Densification

Phase E activities will begin at the time when activities associated with the ATS-F have been completed. It is expected that Phase E activities will be essentially the same as those described in Phase C except that during the latter time period the S-Band ground tracking network stations should all be modified compatible with the GEOS-C instrumentation and will assume a more active role.

INVESTIGATION PLANS

Introduction

In support of the GEOS-C Mission objectives proposals were solicited in thirteen specific investigation categories with provision for investigations in other categories if these could be shown to be compatible with long range Earth and Ocean Physics Application Program objectives. The thirteen specific investigation categories can be summarized as follows:

Ocean Geoid Determination

This proposal category includes all proposals for the determination of the geometry of mean sea level using altimetry data alone or in combination with other data types. The satellite altimeter observations will provide measurements of the height of the satellite above the ocean surface. This data can be used directly to estimate the ocean geoid, provided the satellite position can be determined with sufficient accuracy and/or errors in satellite position corrected for. Investigations in this category may call for the combination of altimeter information with geoid information obtained from existing surface gravimetry, satellite gravity field information, deflection of the vertical information and geocentric station position. The computation of improved satellite gravity fields and station positions should not be included within this investigation category.

One of the important results expected to be obtained from the GEOS-C altimeter is improved definition of the ocean geoid. At present worldwide knowledge of the ocean geoid is only available from satellite gravity field data which, at best, define variations with widths of the order of 1500 kms or larger. Over restricted areas of the world, where dense surface gravity data is available, detailed geoids can be computed defining geoid variations with widths down to 100 kms or smaller. These detailed geoids in local areas have demonstrated that geoid variations of 10 to 20 meters are commonly generated by the wavelengths of less than 1500 kms and are not present in the satellite fields. It has also been shown that even wavelengths of less than 100 kms can, at times, produce variations of up to 10 meters. Therefore, the satellite altimeter with precision and/or accuracy of 1 to 2 meters has the potential for greatly increasing our knowledge of the ocean geoid in those substantial parts of the ocean where no detailed surface gravity exists as well as contributing to increased accuracy in those areas where surface gravity and other types of gravity data exist.

Determination of geoid heights from altimeter measurements requires that the altimeter measurements be reduced in conjunction with satellite orbit information. Questions exist as to: (1) the best method of reduction to eliminate possible systematic orbit and altimeter errors, (2) the best set of parameters to represent the geoid, and (3) the best method for combination of altimeter data with other types of data for improved geoid determination. Ten GEOS-C investigations were proposed in the geoid computation area. These investigations represent a number of approaches to geoid determination from altimeter data and are expected to provide answers to the questions posed above. In order to answer the questions posed, evaluations must be made of the actual altimeter results. Several investigations have as their objective the carrying out of comparisons of results with external standards in order to make such evaluations.

Ocean Tides

Repeated measurements over a section of the ocean using the GEOS-C altimeter has the potential for allowing determination of the time variable effects of the tidal attractions of the sun and moon on sea surface topography. At present most measurements of ocean tides are made at coastal stations where the tidal effects are strongly influenced by local bathymetric effects. Although several theories exist which permit theoretical computation of deep ocean tides only limited numbers of measurements of deep ocean tides have been made, utilizing bottom tide meters.

The satellite altimeter has the potential for rapid global determination of ocean tides. To be of maximum use, accuracies of the order of 10cm will be required for altimeter derived tidal measurements. However, GEOS-C even with the lesser accuracy of its altimeter should allow evaluation of various techniques for recovery of tide data from satellite altimeter measurements. To be of maximum value tidal analyses of GEOS-C altimeter data must be carried out in areas where ground truth in the form of bottom tide meter data is available. Five investigations in this category were proposed.

Sea State Determinations

In addition to giving the distance between the spacecraft and the ocean surface, the GEOS-C altimeter data, through analysis of the characteristics of the return pulse, is expected to provide information on the sea state. In particular, information on mean wave height, wave period, and wave propagation direction may be determinable. Although theoretical studies and aircraft radar altimeter data analyses have been carried out, considerable effort is needed to determine the degree to which various types of sea state data can be extracted from a satellite altimeter and to identify the best methods for carrying out extraction of the information. The bulk of the ten investigations proposed on GEOS-C for sea state determination analyses are aimed at evaluation of feasibility and identification of best methods through comparison of results obtained from the GEOS-C altimeter with ground truth information on sea state and with data obtained from aircraft-borne radar instruments. In addition to analysis of GEOS-C data in terms of sea state parameters, the objectives of investigations include development of information for use in the design of future satellite radar altimeters and determination of potential bias introduced into altimeter sea surface topography determinations due to sea state.

Quasi-Stationary Departures from the Marine Geoid

This proposal category includes all altimeter analyses designed to investigate non-periodic deviations of sea level from an equipotential surface. It also includes analyses of altimeter data to determine sea slopes associated with such phenomena as currents and wind setup. It does not include analyses relating to wave pehnomena, ocean tides, or investigations directed specifically to the determination of the geoid.

The sea surface topography which will be measured by the GEOS-C altimeter is a function primarily of variation of the force of gravity over the earth's surface, changes in atmospheric pressure from point to point on the ocean surface surface, density structure of the water column, surface wind effects, dynamical effects due to ocean currents, and tidal effects. If only gravitational forces (including rotation) were present, the sea surface topography would be coincident with the geoid. The effects of atmospheric pressure variations, wind forces and tides are time variable with a reasonably high temporal frequency. The effects of density structure of the water column and currents are usually considered to be quasi-stationary departures from the geoid, even though the effects of currents do shift over restricted areas of the surface. One of the primary aims of the Earth and Ocean Physics Applications Program is to determine, from altimeter measurements, departures of sea surface topography from the marine geoid due to water motion. The reason for this interest lies in the fact that the velocity and volume of water in motion can be infered from these departures. Although the GEOS-C altimeter is not expected to be accurate enough to provide information which is scientifically useful, it is expected to be accurate enough to test out the concept and permit development of methodologies which can be used with data from latter, more accurate, satellite altimeters. Two investigations are planned in this category.

Gravity Model Improvement

This proposal category includes all analyses of GEOS-C altimeter and tracking data whose ultimate objective is the determination of an improved earth gravity field. These include both normal perturbation analyses combining GEOS-C tracking data from other satellites and analyses in which the altimeter geoid height information, SSE rate information or other tracking data are combined with existing information for gravity field improvement.

Improvement of the existing gravity models is required to achieve EOPAP Program goals from three viewpoints. First, satisfaction of a number of EOPAP goals requires improved satellite orbit determination which is, to a large extent, dependent upon an improved gravity field. Second, determination of effects of ocean currents on sea surface topography requires high accuracy geoids with which altimeter derived sea surface topography can be compared. Increased geoid accuracy requires increased accuracy in knowledge of the gravity field. Finally, interpretation of an improved gravity field offers the potential of increased understanding of platetectonics and, therefore, of the mechanisms producing earthquakes.

Gravity field information can be derived from GEOS-C in three ways: (1) By combining information on the perturbations of GEOS-C from tracking data with data from other satellites in a general perturbation analysis; (2) By analysis of satellite-to-satellite tracking data in the same manner as Lunar Orbiter and Apollo data was analyzed to obtain residual line-of-sight accelerations or compatible gravity anomaly information. Six GEOS-C investigations fall within these areas. Their proposed investigations often include the combination of GEOS-C data with gravity field information from other sources.

Geological Investigations

One important use of the geoid results to be derived from the GEOS-C altimeter data will be interpretation in terms of the geological and geophysical significance of the results. The GEOS-C altimeter results can be of particular value in extending information to areas where little or no surface gravity presently exists. Two investigations were proposed in this category.

Solid-Earth Dynamics

This proposal category includes all analyses involving the determination of earth tides, polar motion, and changes in rotation rate of the earth. It also includes determination of very precise positions on the earth's surface using GEOS-C tracking data for such purposes as determination of fault motion and crustal plate motion.

High precision tracking of the GEOS-C satellite, particularly by the submeter precision laser sytems, will allow derivation of improved information on the dynamics of the solid earth. Determinations can be made of the gravitational and geometric effects of solid earth tides and of the motions of the earth's pole including chandler motion, yearly motion, and the diurnal wobble. Four invesitgations were proposed in this category.

Intercomparison, Evaluation and Calibration of Instrumentation Systems

This investigation category includes all investigations whose objective is the evaluation and calibration of altimeter, satellite-to-satellite tracking and ground tracking instrumentation to be used with the GEOS-C mission. This includes both evaluation of the on-board instrumentation and the ground systems. In this investigation category are placed all instrument intercomparison investigations and studies related to instrumentation technology.

The GEOS-C Project will undertake the primary evaluation and calibration activity with respect to the radar altimeter. Six investigator are planned to be associated with evaluation and calibration activities relative to ground tracking instruments and the satellite-to-satellite experiment. Calibration and evaluation of ground tracking instruments can be carried out by intercomparison analyses. These can involve both co-located intercomparisons and intercomparisons involving reference orbits. Since the satellite-to-satellite experiment involves new instrumentation, special emphasis will be given to evaluation and calibration of these results.

Ground Truth Determination

This investigation category includes all investigations whose objective is the collection of data from ground, ship, and aircraft based systems and the use of this data to evaluate the characteristics of the satellite systems.

In order to calibrate, evaluate, and utilize data taken by instruments on board the GEOS-C spacecraft, it will be necessary to have available certain types of ground truth for comparative purposes. Three investigators have proposed to provide some of this ground truth data.

Tracking Station Location Improvement

This investigation category includes all investigations whose primary objective is the determination of the location of tracking stations where the objective is geodetic in nature and is not for earth dynamic purposes.

A number of types of tracking data taken using the GEOS-C satellite can be used to provide improved station location information which will be useful in support of altimeter calibration and to support other project objectives. GEOS-C will provide data from new stations, data of higher accuracy than previously available, and data from new instrumentation types such as VLBI measurements. Five investigations have been proposed in this category.

Orbit Determination Improvement

This proposal category includes all investigations whose end objective is orbit determination improvement. Indirectly, GEOS-C can be expected to support improved orbit determination by providing improved gravity field information. However, this category will emphasize new types of tracking information such as the SSE and altimeter data and its capability to support improved orbit determination. Two investigators propose to study the use of GEOS-C data for this purpose.

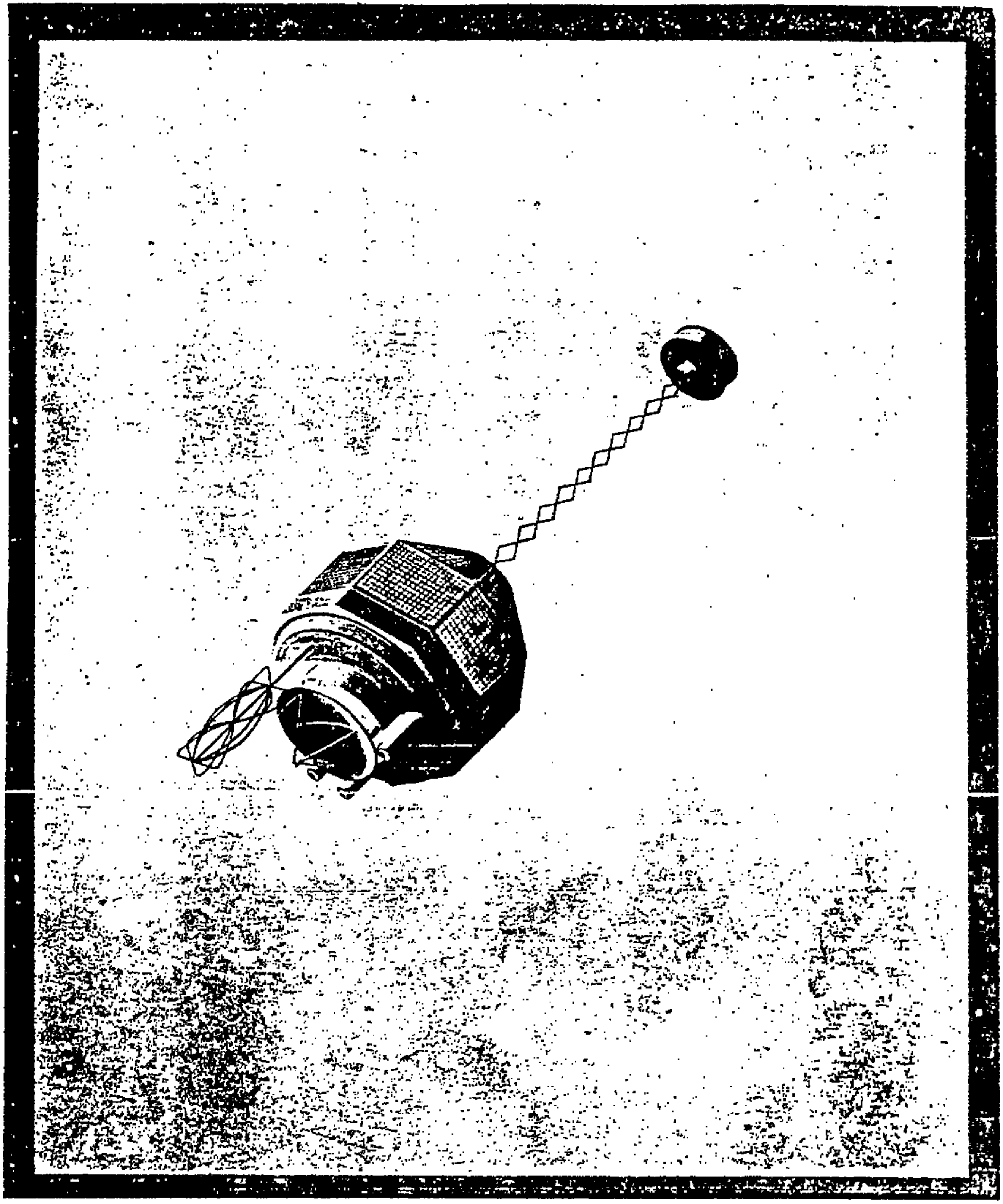
Data Management/Information Processing

This proposal category includes investigations whose objective is the development of methods and techniques for managing and processing the data taken by the various instrumentation on the GEOS-C spacecraft. This includes the development of data editing and pre-processing techniques. Specifically, investigations are directed toward those systems expected to be most useful in future earth and ocean physics applications activities and involve advanced techniques applicable to future activities.

One investigation falls in the general category of data management and/or information processing relative to the altimeter.

Unique System Investigations

Certain GEOS-C investigations are proposed which are uniquely associated with a particular instrumentation and do not fit into any of the preceeding twelve categories. Two investigations are proposed in this category and deal with the C-Band and Altimeter systems.

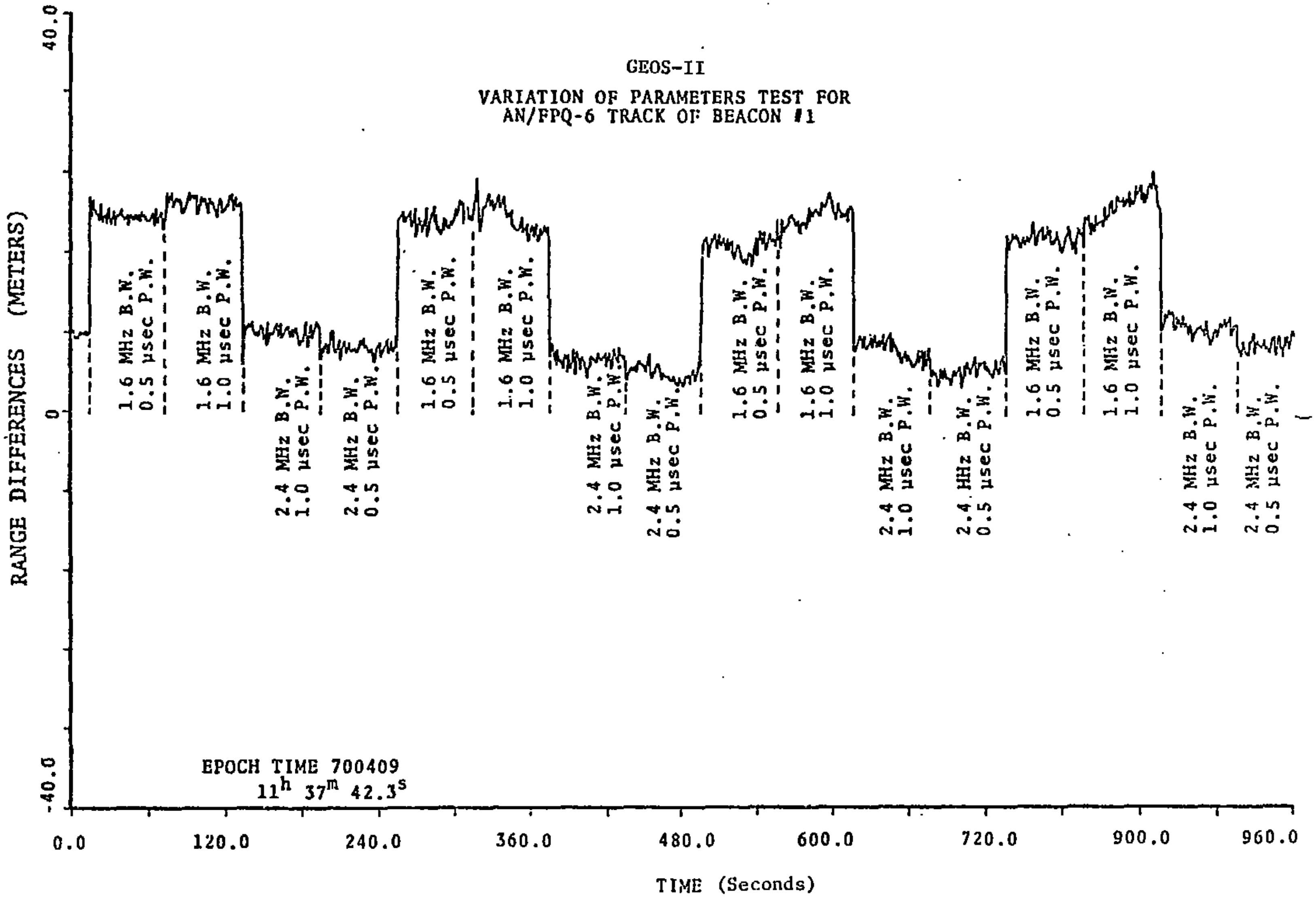


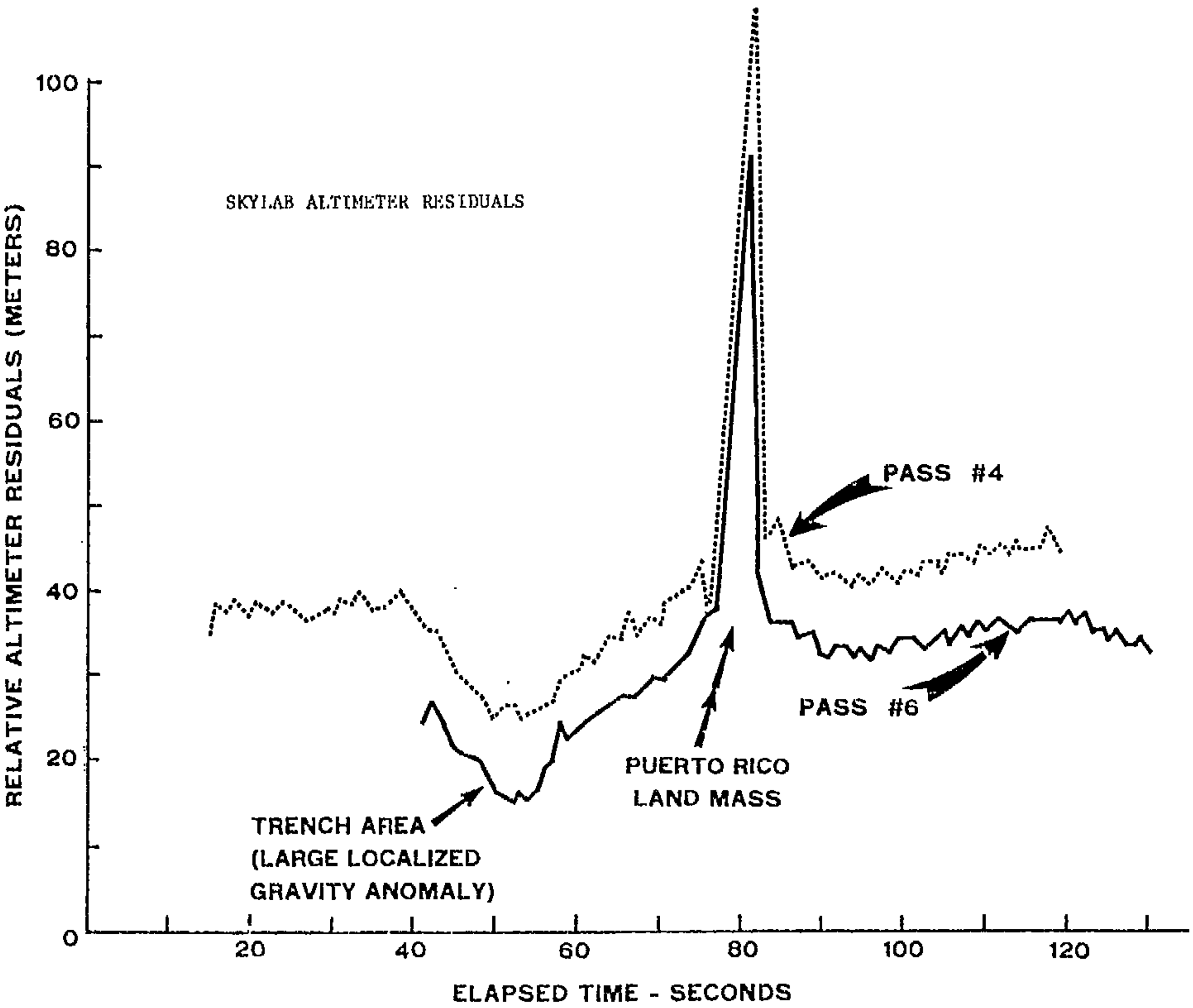
Slide 1

GEOS-C SPACECRAFT

GEOS-II

VARIATION OF PARAMETERS TEST FOR
AN/FPQ-6 TRACK OF BEACON #1




SKYLAB ALTIMETER RESIDUALS
RELATIVE ALTIMETER RESIDUALS (METERS)
0
20
40
60
80
100
ELAPSED TIME - SECONDS
20
40
60
80
100
120
PASS #4
PASS #6
PUERTO RICO
LAND MASS
TRENCH AREA
(LARGE LOCALIZED
GRAVITY ANOMALY)

GEOS-2 C-BAND TRACKING ACTIVITIES

AGENCY	USABLE PASSES	TRACK TIME (SEC)	DATA (SEC)	AA*	BB*	CC*	DD*	EE*	FF*
ETR	568	512124	424798	2	14	30	8	467	329
WTR	181	140539	137448	7	10	10	23	145	307
MSFN	1102	888951	680993	8	25	16	18	366	329
NWAL	722	818904	520635	5	18	95	4	269	158
PMR	329	204893	192199	2	8	15	6	208	519
WSMR	59	48402	49235	3	0	3	1	63	42
EDAFB	6	1327	1361	0	2	1	1	3	28
FRC	67	44733	38557	5	6	0	2	35	32
SHIPS	222	178474	167743	11	11	4	9	98	167
CNES	71	66443	55145	0	6	6	4	52	116
WRE	44	8135	14935	3	0	0	0	36	23
RAE	6	1930	1783	3	1	48	0	40	31
TOTALS	3377	810 HRS	635 HRS	49	101	228	76	1782	2081

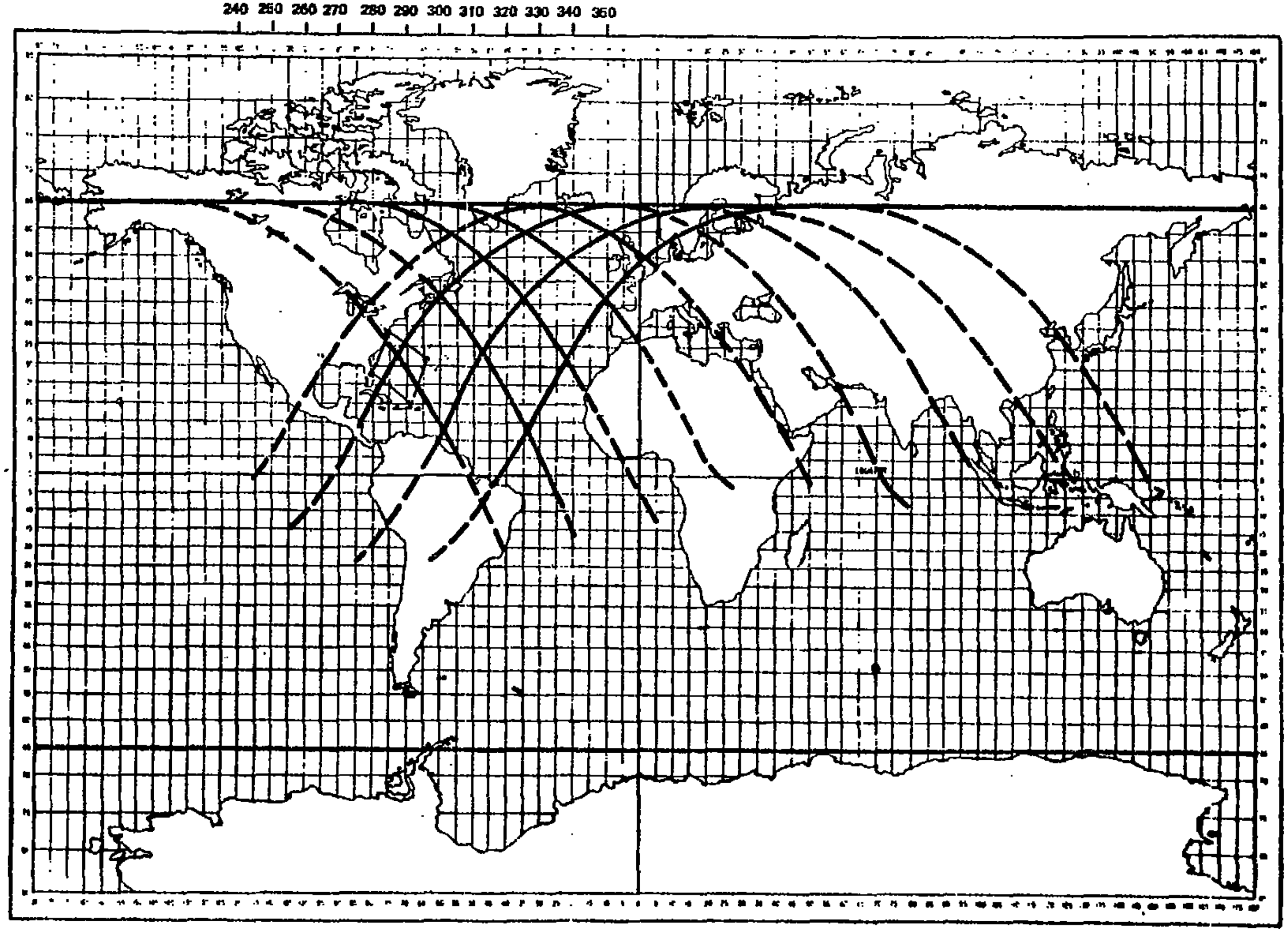
* CODE	DESCRIPTION
AA	Acquisition Problem
BB	Radar Problem
CC	Priority Scheduling Problem
DD	Spacecraft Problem
EE	Deleted or Cancelled
FF	Other or Unknown

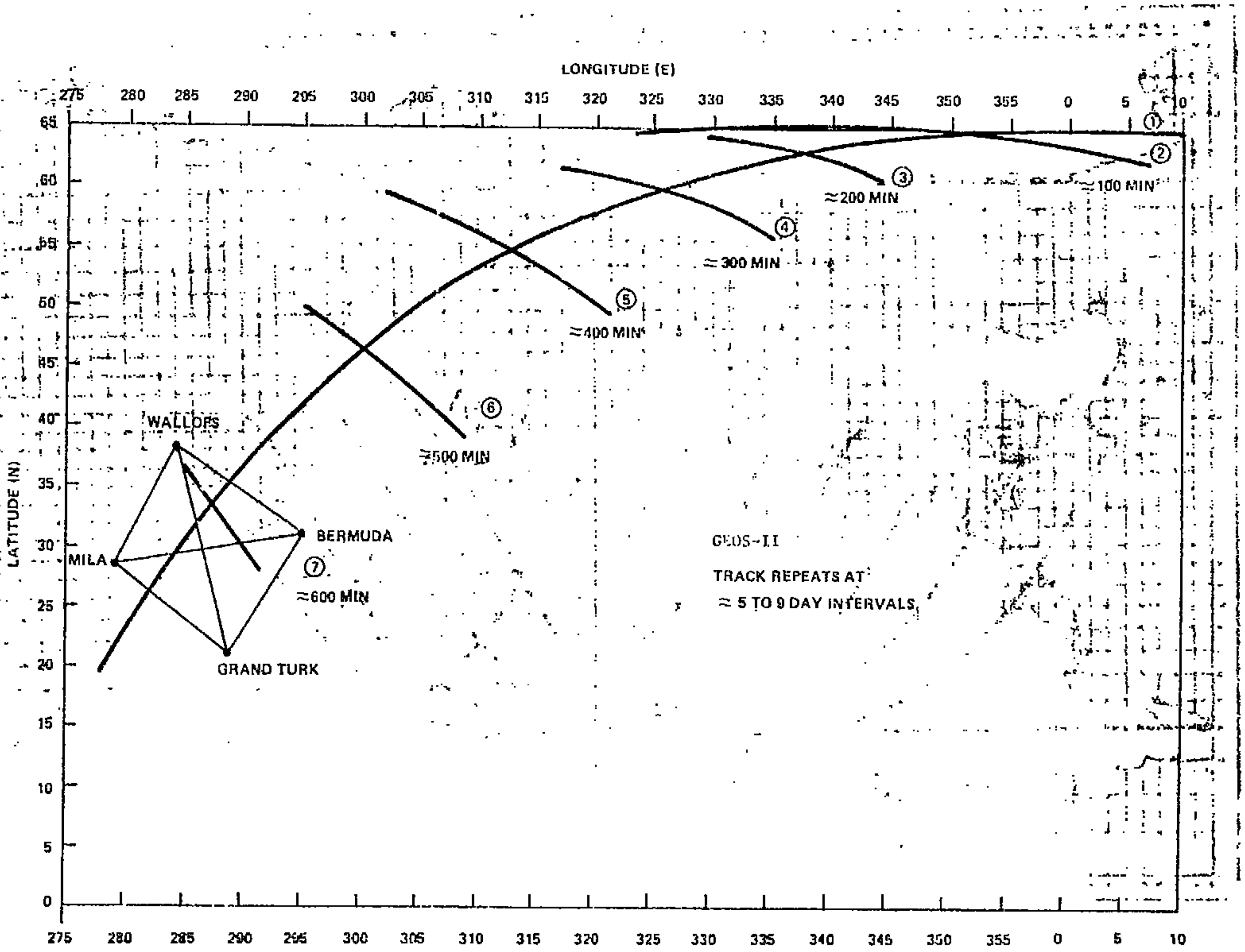
GEOS-II TRACKING DATA

SUMMARY OF DATA AT WALLOPS SORTED BY AGENCY

AGENCY	USABLE	TRACK TIME	DATA	AA	BB	CC	DD	EE	FF
ETR	244	157161	155876	0	1	0	1	1	18
WTR	58	46562	45799	0	0	0	0	0	12
MSFN	802	613635	465756	1	0	0	1	0	38
NWAL	622	749761	452713	0	0	3	1	0	20
PMR	80	41232	36853	0	0	0	0	0	27
WSMR	2	1072	830	0	0	0	0	0	3
EDAFB	2	626	626	0	0	0	0	0	0
FRC	30	20483	15267	0	0	0	0	0	1
SHIPS	1	650	710	0	0	0	0	0	0
CNES	2	1730	1790	0	0	0	0	0	2
WRE	34	5462	11168	1	0	0	0	0	0
RAE	6	1930	1783	0	0	0	0	0	13
TOTALS	1883	455 HRS	330 HRS	2	1	3	3	1	134

NORMAL CALIBRATION MODE OF OPERATION





CALIBRATION PASSES FOR ALTIMETER STABILITY EVALUATION

C-BAND RADAR PARTICIPATION REQUIREMENTS

The following minimum complement of C-Band radars is required for the operational lifetime of the GEOS-C radar altimeter.

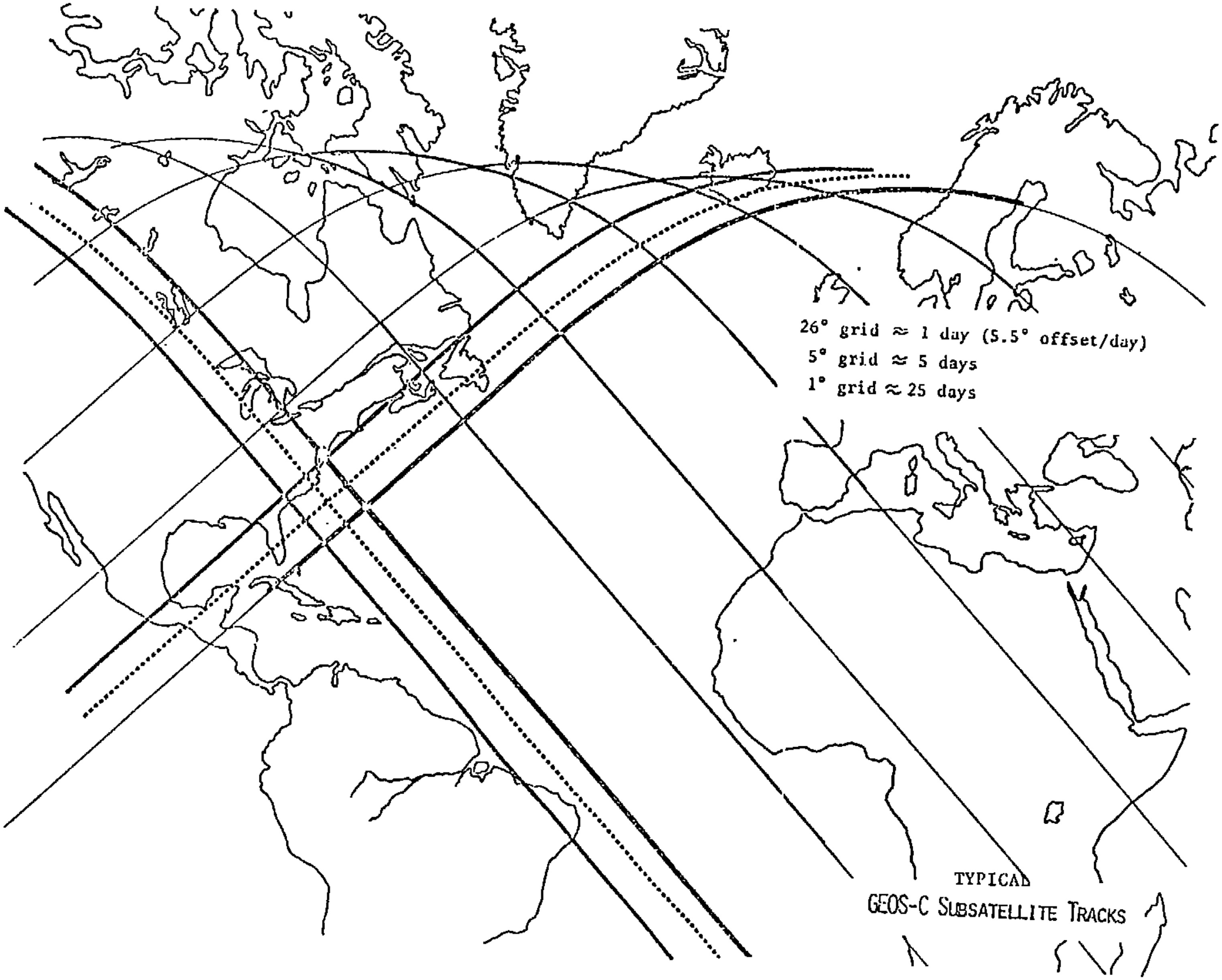
Radar	Agency	Location	Anticipated Usage Avg. Tracks per Day
NWAL 18	NASA/WLPS	Wallops	2 - Mission lifetime
NWAL 13	NASA/WLPS	Wallops	3 - Mission lifetime
NBER 05	NASA/GSFC	Bermuda	3 - Mission lifetime
NTANAN	NASA/GSFC	Tananarive	1 - Mission lifetime
NELHAR	NASA/FRC	Ely, Nevada	1 - 6 months
ETRMRT	AFETR	Merritt Island	3 - Mission lifetime
ETRGRT	AFETR	Grand Turk	3 - Mission lifetime
ETRANT	AFETR	Antigua	3 - Mission lifetime
ETRASC	AFETR	Ascension	1 - 6 months
WTRPPQ	AFWTR	Pillar Point	1 - 6 months
WTRVAN	AFWTR	Vandenberg	2 - 6 months
WTRCAN	AFWTR	Canton Island	2 - Mission lifetime
WTRKPT	AFWTR	Hawaii	2 - Mission lifetime
KWJLYN	AKWR	Kwajalein	1 - 6 months
MPS-36	WSMR	White Sands	1 - 6 months
NCARNV or WOOR 38	NASA/GSFC WRE	Carnarvon Red Lake	2 - Mission lifetime
PMRJ 13	PMR	Johnston Island	1 - 6 months

Several other radars which are highly desirable include:

KOUROU	CNES	Kourou	1 - 6 months
HOURTN	CNES	France	1 - 6 months
CNESAZ	CNES	Azores	1 - 6 months
MPS-36	DFVLR	Germany	1 - 6 months
FPS-16	RAE	England	1 - 6 months
MPS - 36	WSMR	Green River, Utah	1 - 6 months

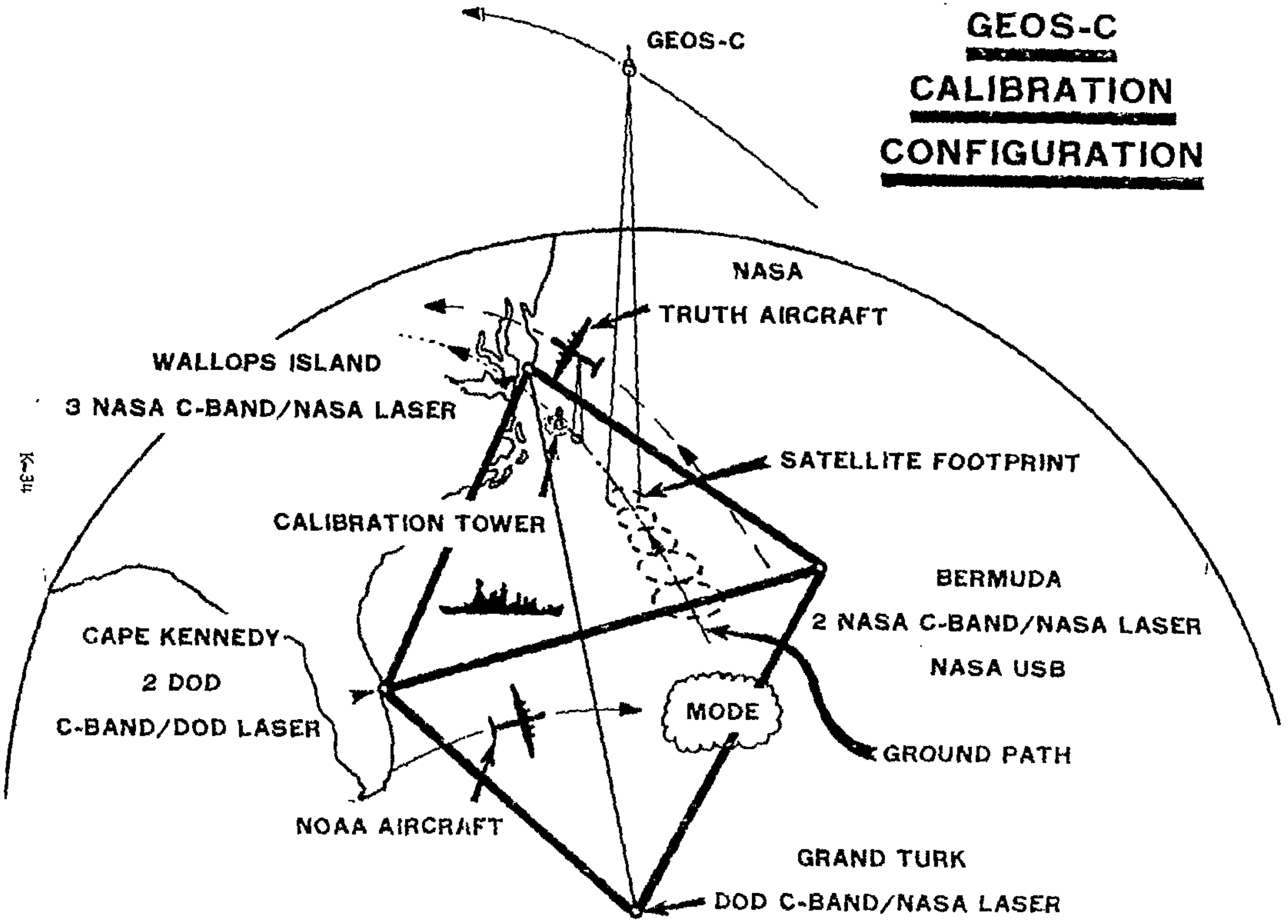
GEOS-C
ALTIMETER SYSTEM CHARACTERISTICS

CHARACTERISTIC	LONG PULSE MODE	SHORT PULSE MODE
OUTPUT TUBE	MAGNETRON	TRAVELING WAVE
OUTPUT POWER	2 Kw	2.5 Kw
PULSE WIDTH	200 N SEC.	12 N SEC.
PRF	100 PULSE BURSTS/SEC. OF 16 PULSES/BURST	100 PPS
ACQUISITION TIME	<5 SEC.	<5 SEC.
OUTPUT (ALTITUDE)	32 BIT AVERAGE	32 BIT AVERAGE
NOMINAL AVERAGE TIME	1 SEC.	0.1 SEC.
RANGE RESOLUTION	6.25 N SEC.	1.56 N SEC.
RANDOM ERROR CORRELATION	<0.05	<0.33
PRECISION	<1 m	<0.6 m



TYPICAL
GEOS-C SUBSATELLITE TRACKS

GEOS-C CALIBRATION CONFIGURATION



APPENDIX L

GEOS-C C-BAND OPERATIONS/SUPPORT

By
BEN JACKSON

NASA/Wallops Station
Wallops Island, Virginia 23337

C-BAND EXPERIMENT SUMMARY

THE GEOS-C SATELLITE WILL BE EQUIPPED WITH BOTH A COHERENT (VEGA MODEL 355C) AND A NON-COHERENT (VEGA MODEL 313C) C-BAND TRANSPONDER. THE CAPABILITY OF C-BAND RADARS AS VALUABLE GEODETIC INSTRUMENTS, WHILE TRACKING A NON-COHERENT TRANSPONDER, WAS WELL ESTABLISHED DURING THE GEOS-B C-BAND SYSTEMS PROJECT. THE UTILIZATION OF THE COHERENT TRANSPONDER WILL RESULT IN C-BAND TRACKING DATA, WHICH IS SIGNIFICANTLY MORE USEFUL AND ACCURATE, AND, WHICH WILL ALSO PROVIDE AN ADDITIONAL MEASUREMENT (RANGE RATE) FROM COHERENT SIGNAL PROCESSOR AND VELOCITY EXTRACTION SUBSYSTEM EQUIPPED RADARS.

DATA COLLECTION, IN SUPPORT OF BOTH THE ALTIMETER CALIBRATION EXERCISE AS WELL AS THE ALTIMETER EXPERIMENTS AND IN SUPPORT OF A COORDINATED SERIES OF INTER-RELATED C-BAND INVESTIGATIONS, WILL BE CONDUCTED AS A PART OF THE GEOS-C C-BAND EXPERIMENT. THE SERIES OF C-BAND EXPERIMENTS ARE EITHER NATURAL EXTENSIONS OF EFFORTS PREVIOUSLY CARRIED OUT DURING THE GEOS-B C-BAND SYSTEMS PROJECT, OR ARE NEW INVESTIGATIONS WHICH DERIVE FROM THE USE OF THE COHERENT C-BAND TRANSPONDER.

THE FOLLOWING IS A GENERAL DESCRIPTION AND BREAKDOWN OF THE PROPOSED ACTIVITIES INVOLVED IN THE OVERALL C-BAND EXPERIMENT.

PRE-LAUNCH ACTIVITIES

DURING THE TIME PRECEEDING LAUNCH, THE EMPHASIS WILL BE ON GATHERING AND ANALYZING GROUND CALIBRATION DATA, DEVELOPING THE CALIBRATION AND OPERATIONS PROCEDURES DOCUMENTS, AND DEVELOPMENT OF THE DATA CORRECTION PROCEDURES TO BE USED FOR THE ENTIRE MISSION. IT IS PLANNED THAT THESE PROCEDURES WILL BE PUBLISHED BY THE GEOS-C C-BAND EXPERIMENT MANAGER AND DISSEMINATED THREE MONTHS PRIOR TO LAUNCH.

IN ADDITION, C-BAND TRACKING OF THE GEOS-B SATELLITE WILL BE CONDUCTED AS A PRE-MISSION SIMULATION IN CONJUNCTION WITH THE ALTIMETER CALIBRATION AREA SIMULATION.

QUICK-LOOK ACTIVITIES

DURING THE 90-DAY ALTIMETER CALIBRATION PERIOD, DATA FROM THE C-BAND RADARS TAKEN AND PROCESSED IN ACCORDANCE WITH THE AFOREMENTIONED PROCEDURES WILL BE ANALYZED AND ANY REFINEMENT TO THE PROCEDURES COORDINATED WITH THE GEOS-C C-BAND EXPERIMENT MANAGER. THE EMPHASIS DURING THIS TIME PERIOD WILL BE PRIMARILY ON OPERATIONAL SUPPORT TO THE ALTIMETER CALIBRATION EFFORT WITH CONTINUED ACTIVITIES TOWARD C-BAND CALIBRATION. DATA FROM THE ALTIMETER CALIBRATION MISSIONS WILL BE SUFFICIENT FOR THE DESIRED ACTIVITIES TOWARD REFINEMENT OF THE C-BAND CALIBRATION.

NORMAL POST-LAUNCH ACTIVITIES

FOLLOWING THE 90-DAY ALTIMETER CALIBRATION PERIOD, SCIENTIFIC DATA COLLECTION WILL BE INITIATED IN ACCORDANCE WITH THE REQUIREMENTS OF THE EXPERIMENT OBJECTIVES,

OBJECTIVES

SPECIFICALLY, THE C-BAND SYSTEMS WILL BE UTILIZED BY NASA AND THE USER AGENCIES TO ACCOMPLISH THE FOLLOWING OBJECTIVES:

(A) TO PROVIDE DATA TO BE USED IN THE DETERMINATION OF HIGHLY PRECISE ORBITS, TO ASSIST IN THE ACCOMPLISHMENT OF THE CALIBRATION AND EVALUATION OBJECTIVES OF THE GEOS-C ALTIMETER SYSTEM PROJECT, AND TO ASSIST IN THE ACCOMPLISHMENT OF THE GRAVIMETRIC OBJECTIVES OF THE OVERALL GEOS-C PROJECT.

(B) TO BETTER DETERMINE THE ABSOLUTE ACCURACY OF THE INSTRUMENTATION RADAR SYSTEM, DEVELOP REFINED METHODS OF CALIBRATING THESE SYSTEMS, AND IMPROVE THE TECHNIQUES IN PROCESSING THE ASSOCIATED DATA:

(1) TO INTEGRATE, WHERE POSSIBLE, THE TECHNIQUES EVOLVED INTO A PROGRAM TO MAINTAIN THE LEVEL OF RADAR ACCURACY WITHIN GIVEN OR KNOWN TOLERANCES.

(2) TO ASSIST IN THE DETERMINATION OF METHODS FOR RAPID AND ACCURATE CALIBRATION OF C-BAND RADAR SYSTEMS.

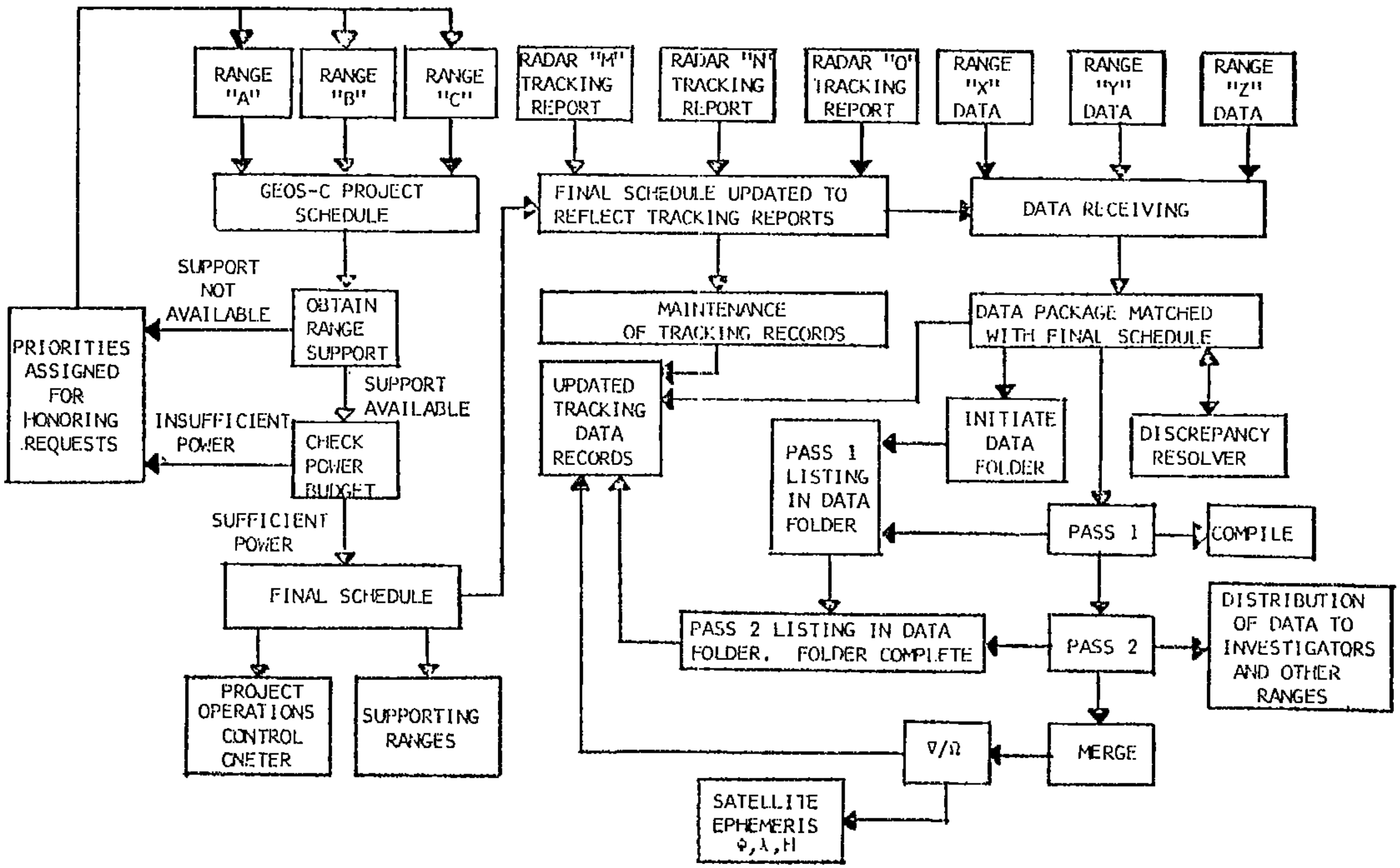
(3) TO EVALUATE THE PERFORMANCE AND ACCURACY OF NEW TRACKING SYSTEMS.

OBJECTIVES (CONT'D)

(C) TO BETTER DETERMINE THE GEODETIC LOCATION OF THE C-BAND RADAR SITES AND THEIR INTERSITE DISTANCES.

(D) TO COMPARE AND CORRELATE RESULTS OBTAINED FROM OTHER GEOS-C TRACKING SYSTEMS WITH THOSE OBTAINED BY THE C-BAND SYSTEMS, WITH PARTICULAR EMPHASIS ON EVALUATING THE POSSIBLE CONTRIBUTIONS OF C-BAND INSTRUMENTATION SYSTEM MEASUREMENTS TO GEODESY.

(E) TO MAKE GENERALLY AVAILABLE THE RESULTS OF BOTH THE C-BAND SYSTEM CALIBRATION AND GEODETIC ENDEAVOR.



GEOS-C C-BAND SCHEDULING & DATA HANDLING PROCEDURES

APPENDIX M

GEOS-C COHERENT C-BAND TRANSPONDER TECHNICAL CHARACTERISTICS

By

ALAN SELSER

NASA/Wallops Station
Wallops Island, Virginia 23337

Coherent C-Band Transponder for GEOS-C

Manufacturer - Vega Precision Laboratories

Model Number - 355C

Primary Mission Requirements:

- Operating Lifetime - 500 hours in orbit over 2 years
- Power Consumption:
  1.5 watts maximum in standby mode
  16 watts maximum in operate mode
- Allowable Frequency Error - 0.6 Hz rms maximum
- Delay variations correctable to within 10 nsec (1.5 meters) over operating lifetime
- Operation with Noncoherent Radars
- Simultaneous Operation with the Noncoherent C-Band Transponder on GEOS-C

OPERATING MODES

- STANDBY - RECEIVER ONLY ON RECEPTION OF 10 VALID INTERROGATIONS:

  TURNS ON OPERATE POWER

  INITIATES 42-SECOND TURN-ON DELAY

- OPERATE

  TRANSPONDER RESPONDS TO ALL VALID INTERROGATIONS AT COMPLETION OF THE 42-SECOND TURN-ON DELAY.

  ABSENCE OF VALID INTERROGATIONS FOR 63 SECONDS WILL CAUSE THE TRANSPONDER TO SWITCH TO STANDBY MODE.

- OVERRIDE

  OPERATE POWER TURNED ON BY SPACECRAFT COMMAND.

  TRANSPONDER WILL RESPOND TO ANY VALID INTERROGATION AFTER THE 42-SECOND TURN-ON DELAY.

  REMOVAL OF OVERRIDE COMMAND WILL RETURN THE TRANSPONDER TO AUTOMATIC STANDBY/OPERATE MODE SWITCHING.

Receiver Characteristics

Frequency	5690 MHz
Bandwidth	16 MHz Nominal
Sensitivity	-67 dBm Minimum
Pulse Code	Double pulse
Code Spacing	8 Microseconds Nominal
Code Accept Range	7.85 to 8.15 Microseconds
Code Reject Range	<7.65 Microseconds >8.30 Microseconds

TRANSMITTER CHARACTERISTICS

FREQUENCY	SAME AS RECEIVED FREQUENCY OVER THE RANGE FROM 5684 TO 5694 MHz
PEAK POWER OUTPUT	> 115 WATTS
PULSE WIDTH	455 NANOSECONDS NOMINAL
PULSE WIDTH STABILITY	± 25 NANOSECONDS
OVERINTERROGATION PROTECTION	2000 PPS
BLANKING	50 MICROSECONDS
FREQUENCY ERROR	< 0.4 Hz RMS
INTERLINE NOISE	> 20 DB BELOW CARRIER (40 Hz BANDWIDTH)

Delay Characteristics

Fixed Delay	2.5 Microseconds Nominal
Delay Variation with Signal Level	70 Nanoseconds (10.7 Meters) (from -20 to -60 dBm)
Delay Variation with Temperature	35 Nanoseconds (5.3 Meters)
Delay Jitter (Noise) as a Function of Signal Level	< 5 Nanoseconds (.8 Meters) RMS (from -20 to -45 dBm)
	< 10 Nanoseconds (1.5 Meters) RMS (from -45 to -60 dBm)

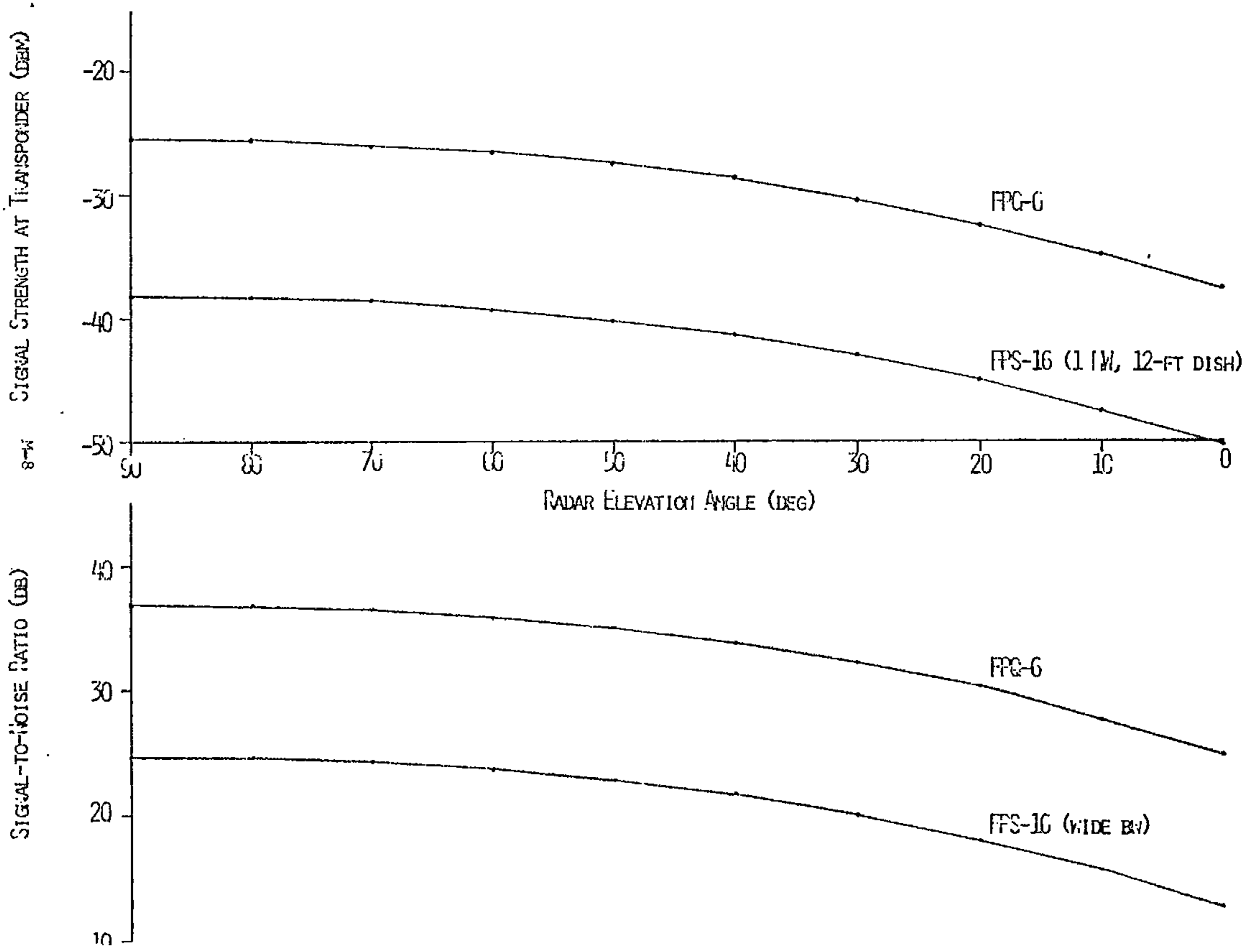
Telemetry Functions

- Input Voltage
- Input Current
- Received Signal Strength
- Received Pulse Repetition Frequency
- Peak Power Output
- Local Oscillator Voltage
- Magnetron Filament Current
- Base Plate Temperature

Physical Characteristics

Volume	< 1500 cc
Mass	2.5 kg

COHERENT C-BAND TRANSPONDER FOR GEOS-C LINK CALCULATIONS



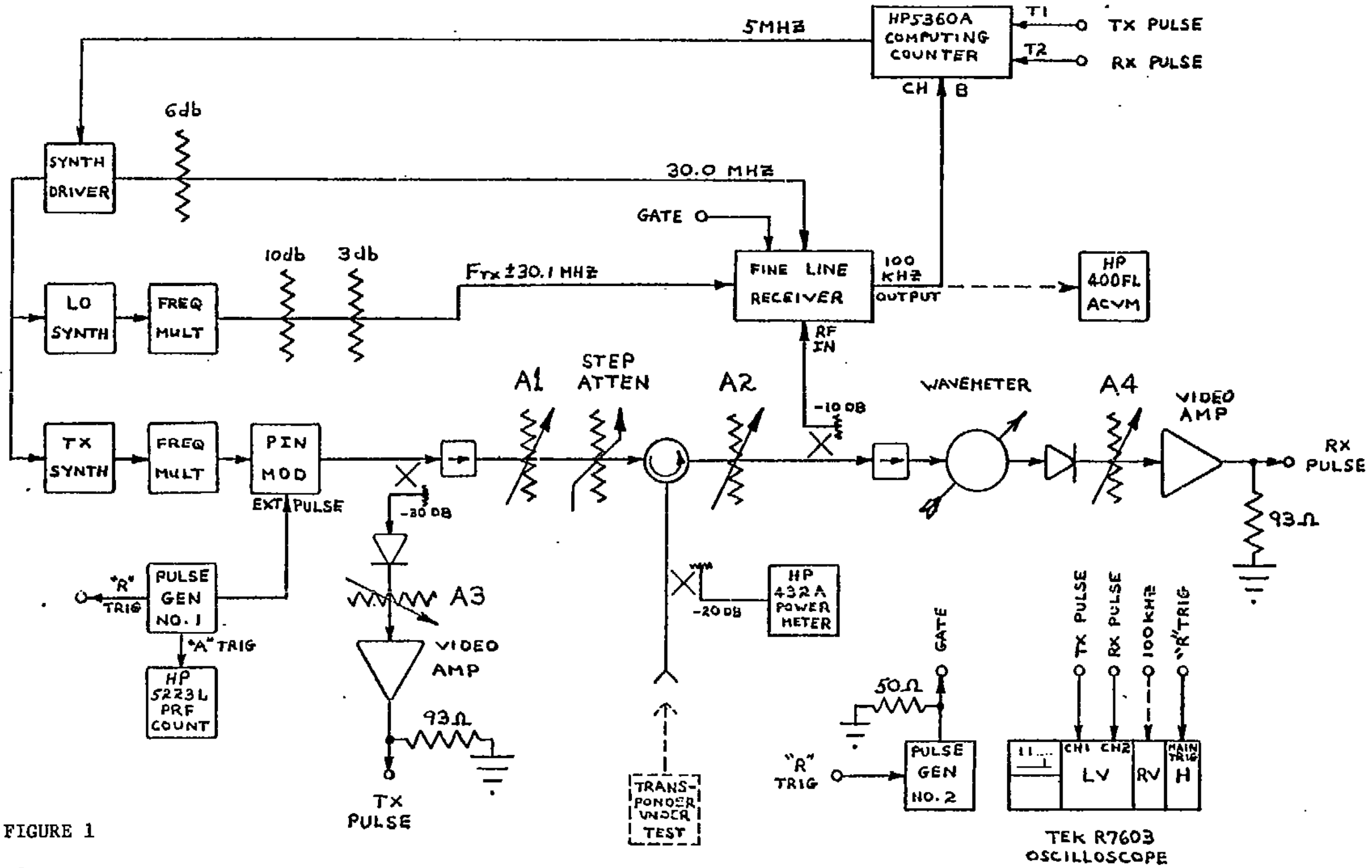


FIGURE 1

C-Band Test Console, Block Diagram,
Spacecraft Level Tests

APPENDIX N

DEFENSE MAPPING AGENCY TEST OBJECTIVES FOR GEOS-C

By

MAJ. LARRY BEERS

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DOD INVESTIGATIONS AND DATA REQUIREMENTS

OBJECTIVE A - LOCAL VERTICAL AND SEA STATE INVESTIGATION REQUIRING SHORT PULSE ALTIMETER DATA WITH COMPLETE WAVEFORM INFORMATION

AREA A - 100 SN, 100 NS

AREA B - 50 SN, 50 NS

AREA C - 50 SN, 50 NS

OBJECTIVE B - SST ACCURACY EVALUATION FOR PRODUCTION OF PRECISE SATELLITE EPHEMERIDES REQUIRING SST DATA AND OTHER TRACKING DATA FOR 18 NS, 18 SN PASSES OVER CALIBRATION AREA AND 18 NS, 18 SN PASSES OVER CONTINENTAL US

OBJECTIVE C - GLOBAL OCEAN SURVEY REQUIRING SHORT PULSE ALTIMETER DATA WITH PARTIAL WAVEFORM INFORMATION OVER A 5° X 5° AND 1° X 1° GRID

OBJECTIVE D - CROSS TRACK DEFLECTION DETERMINATION REQUIRING VERY FINE GRID OF SHORT PULSE ALTIMETER WITH COMPLETE WAVEFORM INFORMATION IN 5° X 5° PROJECTIVE OF AREA C

OBJECTIVE E - SST GLOBAL GEOID REQUIRING GLOBAL GRID OF SST DATA (GRID DIMENSIONS NOT DEFINED)

OBJECTIVE A

- **PURPOSE** - LOCAL VERTICAL AND SEA STATE INVESTIGATION
- **DATA REQUIREMENTS** - SHORT PULSE ALTIMETRY DATA WITH COMPLETE WAVEFORM INFORMATION AS FOLLOWS:
  - AREA A - 100 SN, 100 NS
  - AREA B - 50 SN, 50 NS
  - AREA C - 50 SN, 50 NS
- **SUPPORT COMPATIBILITY**

AREA	SUPPORT REQUIREMENTS	COMMENTS/DEFICIENCIES
C	2 TRACKS/DAY, 4 OF 6 DAYS FOR ≈75 DAYS	COMPLETELY SATISFIED
B	4 TRACKS/DAY FOR ≈25 DAYS	AREA OVER OCEAN COMPLETELY SATISFIED - AREA OVER LAND CANNOT BE COVERED WITH ALTIMETRY DATA
A	4 TRACKS/DAY FOR ≈50 DAYS	CAN PROVIDE REQUIRED DATA IN ≈75% OF AREA ≈25% OF AREA LACKS GROUND STATION COVERAGE

OBJECTIVE B

- PURPOSE - SST ACCURACY EVALUATION FOR PRODUCTION OF PRECISE SATELLITE EPHEMERIDES
- DATA REQUIREMENTS - SST DATA AND OTHER TRACKING DATA FOR 18 NS, 18 SN PASSES OVER CALIBRATION AREA AND 18 NS, 18 SN PASSES OVER CONTINENTAL UNITED STATES. DATA REQUIRED DURING FIRST TWO MONTHS OF OPERATIONS
- SUPPORT COMPATIBILITY -
  - SUPPORT REQUIREMENTS - SST DATA AS SPECIFIED ABOVE
  - COMMENTS/DEFICIENCIES -
    - COVERAGE EXCEEDS REQUIREMENTS IN CALIBRATION AREA
    - COVERAGE EXCEEDS SN PASS REQUIREMENT OVER ≈1/2 OF UNITED STATES
    - REMAINDER OF REQUIREMENT WOULD REQUIRE MORE ATS SUPPORT THAN PRESENTLY CONSIDERED FEASIBLE
    - SST DATA DURING ATS DRIFT WOULD NOT PROVIDE DENSITY REQUIRED AND WOULD BE ACQUIRED TOO LATE IN THE MISSION TO SATISFY THIS REQUIREMENT

OBJECTIVE C

- PURPOSE - GLOBAL OCEAN SURVEY
- DATA REQUIREMENTS - SHORT PULSE ALTIMETER DATA WITH PARTIAL WAVEFORM INFORMATION OVER A 5° X 5° AND 1° X 1° GRID
- SUPPORT COMPATIBILITY -
  - 5° X 5° COVERAGE
    - SUPPORT REQUIREMENTS - APPROXIMATELY 40 DAYS OF DATA RELAY THROUGH ATS DURING ATS DRIFT TO EASTERN HEMISPHERE AT RATE OF 4 TRACKS/DAY
    - COMMENTS/DEFICIENCIES - COMPLETELY SATISFIED IN ATS COVERAGE AREAS; RESTRICTED TO LOW DATA RATE, THEREFORE, PARTIAL WAVEFORM DATA IS LIMITED TO ALL AVERAGE RETURN GATES AND INSTANTANEOUS PLATEAU GATE
  - 1° X 1° COVERAGE
    - SUPPORT REQUIREMENTS - APPROXIMATELY 160 DAYS (80 IN EACH HEMISPHERE) THROUGH ATS AT RATE OF 4 TRACKS/DAY
    - COMMENTS/DEFICIENCIES - REQUIRED COVERAGE LIMITED TO GROUND STATION COVERAGE AREAS; COMPLETE WAVEFORM INFORMATION WOULD BE AVAILABLE IN THESE AREAS; COMPLETE SATISFACTION OF THIS REQUIREMENT WOULD REQUIRE MORE ATS SUPPORT THAN PRESENTLY CONSIDERED FEASIBLE

OBJECTIVE D

- PURPOSE - CROSS TRACK DEFLECTION DETERMINATION
- DATA REQUIREMENTS - VERY FINE GRID OF SHORT PULSE ALTIMETER DATA WITH COMPLETE WAVEFORM INFORMATION IN 5° X 5° PROJECTION OF AREA C
- SUPPORT COMPATIBILITY -
  - SUPPORT REQUIREMENTS - APPROXIMATELY 30 NS, 30 SN TRACKS REQUIRING TWO TRACKS/ FIVE DAYS FOR ≈150 DAYS
  - COMMENTS/DEFICIENCIES - COMPLETELY SATISFIED, CONTINUE TRACKING AT ABOVE RATE FOR AN ADDITIONAL 75 DAYS AFTER SATISFACTION OF OBJECTIVE A - AREA C REQUIREMENT

OBJECTIVE E

- PURPOSE - SST GLOBAL GEOID
- DATA REQUIREMENTS - GLOBAL GRID OF SST DATA (GRID DIMENSIONS NOT DEFINED)
- SUPPORT COMPATIBILITY -
  - SUPPORT REQUIREMENTS - A 5° X 5° GRID IN THE ATS COVERAGE AREAS WOULD TAKE APPROXIMATELY 40 DAYS OF TRACKING WITH ATS DURING ATS DRIFT TO EASTERN HEMISPHERE AT RATE OF 4 TRACKS/DAY
  - COMMENTS/DEFICIENCIES - 5° X 5° GRID COMPLETELY SATISFIED IN ATS COVERAGE AREAS; DATA OBTAINED SIMULTANEOUSLY WITH OBJECTIVE C, 5° X 5° GRID

APPENDIX O

GEOS-C C-BAND WORKING GROUP

7 MARCH 1974 MEETING

Vandenberg AFB, California 93437

AGENDA

GEOS-C C-Band Working Group

March 7, 1974 - 1330-1630 PDT

A. C-Band Experiment Summary

B. Summation, C-Band Systems Objectives

C. Pre-Launch Objectives

D. Quick-Look Activities

E. Normal Post-Launch Objectives

F. Scheduling and Data Handling Procedures

G. Coherent C-Band Transponder (Vega Model 355C)

H. Discussion

GEOS-C C-Band Working Group

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS STATION
WALLOPS ISLAND, VIRGINIA 23337

REPLY TO ATTN OF: PMS (GEOS-C)

MAY 2 1974

TO: Distribution

FROM: PMS/GEOS-C C-Band Subsystems Manager

SUBJECT: GEOS-C C-Band Working Group

The GEOS-C C-Band Working Group Meeting was held on March 7, 1974, at Vandenberg Air Force Base, California, in Building 7000 Theatre, as a part of the SAMTEC Conference on Coherent Radars for Range Instrumentation. Since most of the cognizant Department of Defense C-Band instrumentation personnel were in attendance for the conference, which began on March 5, 1974, it was appropriate to conclude the conference with the C-Band Working Group Meeting.

It was easily apparent, during the entire conference, that the GEOS-C C-Band instrumentation would be of invaluable assistance to all of DOD as a means of calibrating and evaluating the performance and accuracy of their tracking systems. Several requests were made during the conference, by persons not originally members of the Working Group, to attend this session, and 38 persons (see Enclosure 1) were present. Sandia Laboratories and the Defense Mapping Agency were the new agencies represented.

A general summation of the C-Band mission objectives was given and general dialogue regarding the impact of SAMTEC as lead DOD range on scheduling, coordination, and data handling ensued. The basic consensus of opinion by NASA, Wallops, and SAMTEC was that NASA, Wallops, would do all advanced scheduling of DOD radars through SAMTEC. Any changes to the schedule would be done directly between Wallops and the specific range involved with an information copy to SAMTEC. The reverse would hold true for the schedule items originally requested by DOD for tracking support by various support ranges if conflicts arose. All ranges tracking would submit a tracking report at approximately T+1 hour via TWX to Wallops and, if the tracking was in support of NASA, Wallops, use the mails to send the data packet directly to Wallops. Questions arose concerning distant or remote sites, and it was concluded that the same procedures would be utilized for them.

Questions began to arise concerning the lack of formal information at the respective support ranges for the GEOS-C mission, and copies of the Program Introduction (PI) Document was distributed to a representative of each range. This document formalizes the program and it becomes an official support requirement for each range. Suggestions were made that perhaps a GEOS-C team be invited to offer presentations similar to those in the SAMTEC Agenda to the Commanding Officer at each range, or that an invitation be extended to the GEOS-C team to make a presentation to the Range Commanders Conference in the near future.

Despite the factor that expenditures for direct support are required by submission of the PI according to a DOD directive being implemented, commencing July 1, 1974, most persons felt that the DOD requirements on the GEOS-C mission would offset any costs incurred by NASA.

Many topics were openly discussed and explanations offered by H. R. Stanley, W. B. Krabill, and A. R. Selser of NASA, Wallops; W. E. Hawkins and J. Berbert of NASA, GSFC; and the undersigned on the multiple facets of the GEOS-C Program. Listed below are these topics and/or the requirements as stated by the range representatives starred on Enclosure 1.

a. Sandia Laboratories at the Tonopah Test Range requested that they be permitted to commence tracking GEOS-B in preparation for the upcoming GEOS-C mission. The procedure for requesting such support was explained, as well as the available power remaining on GEOS-B, for this tracking. Suggestions were made that they coordinate these tracks for acquisition purposes with SAMTEC and WSMR.

b. The ETR must solve inhouse the interface between Range Measurement Laboratory (RML) and the remainder of the range such that a single scheduling interface be made through L. Ebaugh, AFETR Headquarters.

c. Some arrangement should be made by NASA to identify all support requests as: REQUIRED, DESIRED, or MISSION CRITICAL. It was further suggested that Major L. Beers/DMA attempt to establish military priorities for C-Band support.

d. The required NASA pre-, setup-, and post-calibrations for data collection will be made to DCD and included in the Operations Requirements (OR) Document as specifications for operations in support of GEOS-C. This is essential for ranges having multiplicities of the same type of radars, since each radar has different characteristics. Raw range data should be forwarded to Wallops.

e. The proposed 14-day advanced schedule requirements were requested to be made 30 days to allow advance planning by the support ranges.

f. All ranges have the capability of generating their own angles, if provided either the NORAD or BROUWER elements. BROUWER elements will be provided by the Project through GSFC.

g. A series of coordinated tracks will be set up utilizing GEOS-B to simulate a GEOS-C type operation including data handling. This may have to be done in segments in view of the available power for GEOS-B.

h. Many of the ranges have altered or added to their basic requirements/objectives for the GEOS-C mission and are to supply the undersigned these updated requirements/objectives by the end of March. A short summation of each is indicated below.

(1) ETR - C-Band data for self-calibration and coordination with SAMTEC for USNS ARNOLD. Laser, and possibly Doppler, data is requested from collocated sites.

(2) WSMR - C-Band data for calibration standards and intercomparisons with other ranges.

(3) PMR - C-Band, Doppler, and Laser data coordinating with other ranges. (Doppler needs were passed on to DMA for resolution.)

(4) KMR - C-Band data for self-calibration, Doppler orbits, TM, and altimeter data are requested. The ALCOR radar was mentioned, but efforts are being made by NASA not to utilize this system. (TM, Doppler, and Altimeter needs were passed on to DMA for resolution.)

(5) Sandia - C-Band data for improved station location and calibrations with other ranges (SAMTEC, WSMR).

(6) SAMTEC - C-Band, Altimeter, and Laser data for calibration coordination with other ranges.

Much interest has been generated within the group, and the unanimous consensus of opinion is that these Working Group Meetings should be held every two months throughout the lifetime of the GEOS-C mission, possibly on a range-host rotatable basis.

Earl B. Jackson

Earl B. Jackson

Enclosure